Postural Behavior in Newborn Infants. A Behaviour and Physiological Study

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POSTURAL BEHAVIOUR IN NEWBORN INFANTS

A Behavioural and Physiological Study

Voor Lutje, Alexandra, Jim and Michaël.

STELLINGEN

1. "Variability seems to be the keyword for the functional development of the nervous system... a decrease in variability is one characteristic of the development of the impaired nervous system, leading to stereotypy of responses and reactions, and perhaps also hampering compensation" (Touwen, 1976, Clinics in Developmental Medicine, 58).

2. Een systematische vergelijking van het neurologisch functioneren met de anatomische bevindingen van de axiale computertomografie bij kinderen lijdend aan cerebral palsy brengt nieuwe inzichten in de ontwikkeling van het beschadigde zenuwstelsel; een standaardiseren van de leeftijden waarop deze vergelijkingen gebeuren is ten zeerste aan te raden (bv. 9 maanden en 24 maanden).

3. Biopsiëren van huid of conjunctiva als eerste anatomopathologisch onderzoek bij kinderen verdacht van neuro-degeneratieve aandoeningen blijkt een goede en veilige methode. Zij biedt daarenboven de mogelijkheid tot herhaald onderzoek (Libert,J., Tondeur,M. and Van Hoof,F. Birth Defects, Original article series, in press; Ceuterick, C., Martin, J.J., Casaer,P. and Edgar, G.W.F., 1976, Neuropaediatrie 7, 250-260).

4. Axiale computertomografie uitgevoerd enkele maanden na het optreden van een niet begrepen acuut centraal neurologisch moment bij kinderen, blijkt van groot nut bij het differentiëren tussen vasculaire en andere aetiologieën. De vasculaire stoornissen leiden verbazend snel naar weefselatrofie.

5. In het ontwikkelen van apparatuur voor de studie van fysiologische variabelen bij de mens dient meer aandacht besteed te worden aan electroden en transducers; deze zijn vaak de zwakste schakel in het gehele meetsysteem.

6. De familiale anamnese van erfelijke ziekten is minder betrouwbaar geworden gezien de huidige beperkte gezinsgrootte.

7. Dat de behandeling en de begeleiding van patiënten met spina bifida een taak is voor een team is algemeen aanvaard; dat de begeleiding vanaf de puberteit nieuwe en vooralsnog onopgeloste problemen stelt, wordt thans nijpend ervaren.

8. Het geven van een speen gedurende het klinisch onderzoek, gedurende een gedragsobservatie of gedurende fysiologische metingen bij de jonge zuigeling is meer dan een "zoethoudertje"; het brengt, gewild of ongewild, de zuigeling in een zeer specifieke "state" waarmede rekening moet gehouden worden (dit proefschrift, hoofdstuk 4 en 5).

9. Het bestuderen van de samenhang tussen houding, ademhaling en motoriek in de eerste levensmaanden bij voldragen- en te vroeg geborenen is een logische verdere stap op de in dit proefschrift aangevatte onderzoekslijn.

10. De idee dat "patient-monitoring" een vermindering in het aantal verplegenden tot gevolg zal hebben is onjuist en gevaarlijk.

11. Het bepalen van de bloedspiegels van anti-epileptica is een zeer belangrijk hulpmiddel bij de behandeling van epileptische kinderen; het bijsturen op één enkele bloedspiegelwaarde leidt echter tot een zig-zag verloop in de behandeling.

12. Zolang er Vlamingen zijn die denken dat Groningen de hoofdstad van Friesland is en zolang er Nederlanders zij die denken dat Brussel een historisch franstalige stad is, hapert er iets aan de kulturele betrekkingen tussen Nederland en België.

13. De Kindergeneeskunde in België kende een grote vooruitgang in de laatste jaren; indien zij echter op een internationaal niveau wil komen en blijven, zal, ofschoon er grote economische problemen bestaan, toch een extra, goed geplande, financiële inspanning geleverd moeten worden.

Paul CASAER, Groningen, 26 januari 1977.

RIJKSUNIVERSITEIT TE GRONINGEN

Postural Behaviour in Newborn Infants

A Behavioural and Physiological Study

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Paul Jules Maria CASAER
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The illustrations in this report were made by Mrs. H. Sanders, Mrs. W. Lems, by my former neighbour Mr. E.B. Schmied, by Dr. J.E. Vos, by Mr. L. van Eykern and the "newborns" by Mr. L. Vandeputte.
Photograps were made by Mr. J. Hoks, and by the co-workers of the Central-Photography Departement of the University at Groningen and of the Medical-Photography Departement in Leuven.

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P.C. Leuven, December 1976.

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Chapter 1

PROBLEMS FOR STUDY

1.1. INTRODUCTION

The present study on postural behaviour and postural mechanisms in the newborn is the starting-point of a new research-line in the Department of Developmental Neurology in Groningen, namely the study of the ontogeny of postural behaviour and postural mechanisms in the human. The need for a better knowledge of normal and abnormal postural development and their underlying mechanisms became more and more obvious during previous studies. After the development of standardised neurological examination-techniques for newborns (Prechtl and Beintema, 1964) and for children (Touwen and Prechtl, 1970), a follow-up study, which started 20 years ago, showed that meaningful relations exist between obstetrical and neonatal neurological data(Prechtl, 1965)and between neurological findings early and late in child development (Dijstra, 1960; Touwen, 1972). At the age of 5 years, using free-field observation techniques, Kalverboer (1975) found clear relations between behavioural and neurological findings. This follow-up study provided a wealth of information on the normal and abnormal development of the nervous system in interaction with its environment. The study, however, made it absolutely clear that in infancy an individual prediction of later nervous system functioning, based on the neurological examination, is impossible. Therefore, periodical evaluations of the neurological condition of infants became customary. The problem remains, however, which norms should be used and how the observed facts should be interpreted. Touwen (1976) using a neurological examination technique studied in detail 51 low-risk infants from birth until the age of walking free, and from his results and from his critical analysis of the literature it is obvious that those neurological items, showing an evident developmental sequence in this particular age group, are almost all items related to postural behaviour.

These studies,however, would not have been possible without the introduction of the concept of state.
Newborns have already relatively stable behavioural conditions, which can be classified with the help of descriptive rating scales. In the present study the behavioural states are defined according to the criteria described by Prechtl and Beintema (1964).
- State 1 : eyes closed, regular respiration, no movements.
- State 2 : eyes closed, irregular respiration, small movements.
- State 3 : eyes open, no gross movements.
- State 4 : eyes open, gross movements.
- State 5 : crying.

Newborns change their behavioural states during the neurological examination even when a strictly standardised sequence is followed (Beintema, 1968). Thus the question arose whether those patterns only reflect differences in reactivity of the newborns to the imposed manipulations or are they also the result from differences in brain mechanisms controlling the

behavioural states ?
To answer these questions, sufficiently long observations of infants under well controlled constant conditions were made and simultaneously various physiological concomitants were recorded.
This line of research became greatly facilitated by the development of polygraphic recording techniques and of new methods of data reduction and analysis (Prechtl, 1968; Prechtl et al., 1968, Prechtl et al., 1969, Vos, 1975; Vos et al., 1976; Scholten, 1976). Because the experimental manipulations of humans are only possible to a very limited extent, the need for an animal model to study the development of the behavioural states and of its controlling mechanisms became obvious.
In a critical review of this line of research studying the behavioural states and state-cycling Prechtl concluded that states of the newborn are distinct conditions, each having specific properties and reflecting a particular mode of nervous system functioning. During those studies a possible relation between posture, motility and states became more and more evident, Prechtl (1974) therefore speculated : "It may very well be the case, that the physiological regulation of posture is an essential part of the state organisation ..."

1.2. BASIC CONCEPTS AND TERMINOLOGY

Space — In a study on posture and postural mechanisms the concept of space is essential.

Gravity — One property of space has a key role in this study, namely the vertical, i.e. the direction which parallels the effective field of gravity. With reference to that direction the orientation

Orientation — of an object or a subject is determined.

Localisation — If a more detailed definition of a rigid body in space is required, the co-ordinates have to be defined i.e. the localisation of the object in space.

Configuration — If the object is composed of several parts connected to each other then a detailed definition requires the co-ordinates of the composing elements; in this manner the configuration is described.

Position — The word position will be used in the present study to indicate several categories of orientation : "prone-, supine-, side- and sitting position". Orientation, localisation, configuration, position are used in a passive connotation. By moving an object or a subject, its position can be passively changed. To describe a living thing in space a concept of activity is necessary. The reaction of the living system on the effects of gravity is essential.

Posture — A living being is active in space, it has a posture. Posture is thus position and something active. The position of the body and of its composing elements is determined by a number of passive properties such as the anatomically determined range of movements of the joints, the elasticity of the muscles, of the tendons and of the skin.

Postural mechanisms

Posture requires moreover a number of active postural mechanisms. These postural mechanisms are a group of neuro-motor functions that enable living systems to control their body-posture at rest, during displacement and during active movement.

Postural control system

These functions of the nervous system, of the receptors and of the muscular system form the postural control system. Without going in too much detail at this point, it should be mentioned that the postural control system can be subdivided in three main subsystems.
The first subsystem is the sensory input system, which consists of a series of receptors with their receiving centres in the central nervous system : the vestibular-, the joint receptive-, the tactile-, the proprioceptive-, the visual- an the acoustical system.
Those systems record a subject's orientation in space. The vestibula, by their architectonic and physical characteristics are specifically equipped to record the orientation of the head; together with the proprioceptive and tactile inputs from out of the body, especially from the neck, the spatial orientation and configuration of the body is recorded.
The second major subsystem consists of those central nervous system functions that can be described as the comparator of the out going commands and of the afferent feedback.
The third and last subsystem is the effector-system which continuously adapts and optimizes body posture. A first method to achieve this aim is the generation and modulation of muscle activity.
This aspect of postural control is the main one to be observed in postural behaviour.

Antigravity muscle activity

Muscle activity resulting in a force in the opposite direction of the effective field of gravity can be defined as antigravity muscle activity.
This type of muscle activity is important in the neonatal period since that is the first period in which the developing organism is fully exposed to the effects of the field of gravity.

Efferent control of receptors

Surely as important in this postural control subsystem is a second group of effector mechanisms, namely those functions that continuously adapt the sensitivity of the peripheral receptors, e.g. the control of the muscle spindles.

Postural behaviour

In this report the term postural behaviour will be used to indicate : posture and changes in posture, i.e. the overt behavioural outputs of the postural control system.

For further reading on concepts related to space, posture and postural mechanisms the reader is referred to Howard and Templeton (1966), Roberts (1967), Buytendijk (1971).

1.3. THE ACTUAL QUESTIONS

The actual questions to which I address myself in the present study are : Do human newborns have a body posture ? Is it an "active" posture or merely a passive configuration? and if it is an active posture, can some of the underlying mechanisms be disclosed ?
As mentioned above the results should be a starting-point for an ontogenetic study on postural behaviour and on postural mechanisms.
Why start such a study in the neonatal period ? Why not earlier ? Although it is known that there is prenatal structural and functional development, (see paragraph 6.3.2.) it was still decided to start this study in neonatal life since that is the first moment during human development, in which systematic studies on behaviour and its physiological concomitants are at present feasible.
Why not later ? Postural behaviour is always incorporated in a more global behavioural programme; behavioural programmes become rapidly more and more complex during development. Therefore, it is a challenge to try to derive some basic rules on postural mechanisms, as early as possible, since this might enable us to study how they are incorporated and modified in the mechanism of orienting behaviour, of early visuo-motor interactions and of locomotion.

1.4. THE CLINICAL RELEVANCE

Furthermore, the decision to start the study in the neonatal period is validated by the relevance of the present study for two clinical issues : first for the early diagnosis and early treatment of motor developmental abnormalities and secondly for the optimalisation of the adaptation of very young or very sick newborns to their extra-uterine life.

1.4.1. Early detection and early treatment of motor developmental abnormalities

The problems of children with motor developmental abnormalities can to a large extent be categorised as deviant postural behaviour. This is most obvious in children with Cerebral Palsy, as it is reflected in the at present frequently used definition for this syndrome : Cerebral Palsy is a disorder of movement and posture due to a deficit or lesion of the immature brain (Bax, 1964). This definition is derived from a wealth of clinical observations; one of the earlier and a frequently quoted observation is the study by Little (1861), in which he states that birth injuries may result in mental and motor disturbances in childhood. The only principal difference between the concept of Little and the present concept is that besides adverse factors in the perinatal period, deficits and lesions occurring during early and mid pregnancy and during early infancy are now

included (Bax, 1964, Ingram, 1964, Holt, 1965, Bobath, 1965 and Hagberg et al., 1975 a and b).
How far perceptual deficits, such as visual disturbances, and other sensorimotor interaction difficulties are primarily the results of the structural lesions or are secondarily the consequences of early functional abnormalities is still a question of much debate and a problem for further research (see Abercrombie 1964, Connolly, 1969, Holt (Ed.), 1975).
It is agreed, however, that the later effect plays an important role; inadequate postural behaviour early in infancy interferes with the development of adequate motor behaviour and its underlying sensorimotor interactions; in another frame of reference such a deficit interferes with smooth social interaction and early social development.
A basic prerequisite for complex motor behaviour is the development within the nervous system of reliable and accurate objective representations of the external world. Connolly (1969,1975), after reviewing the available evidence both from experimental animal work and human research, concluded that such representations are the result of all those encounters of a child with his environment, during which motor problems have to be solved.

The organisation of a posture in the extrauterine environment is one of the first problems an infant has to solve.
That the amount of success which a baby has in the organisation of his postural behaviour might be relevant for his development will be illustrated with an example of normal and abnormal postural behaviour in the first days of life. As will be demonstrated in the present study, a newborn carried by his care-giver has a small but definite degree of postural control.
The normal baby in contrast to the abnormal one is neither too floppy nor too rigid, so it is easy to carry him against the shoulder or in the arms. As a result of this new orientation and of the reaction and the adaptation of the newborn to this new orientation his central nervous system receives a new set of information about the environment and about its body in that environment.
Furthermore, a newborn resting in the arms of his care-giver is in the ideal position for early visual and social interaction.
In contrast an abnormal newborn with neck-extensor hypertonia will show, at each occasion when he is brought in a vertical position a retroflection of the head. For the care-giver it is not easy to carry or to cuddle such an infant. This inadequate postural behaviour does not only accentuate the neck-extensor hypertonia but it interferes with visual and social interaction with the care-giver.
The optimalisation of sensori-motor development and the prevention of secondary effects of abnormal postural behaviour are the main reason to advocate early treatment of motor developmental abnormalities. Before treatment can be started, however, abnormal postural behaviour has to be recognised. For this purpose a detailed knowledge of normal early postural behaviour is required. This was the most important reason for starting the present study in normal human neonates.

A second reason might be that a better knowledge of the mechanisms underlying normal postural behaviour might help to strengthen the concepts on which therapeutic schemes for the treatment of abnormal postural behaviour are based. At present they are based on a vast clinical experience, on a high degree of intuition, and on a lot of common-sense (for a recent review of the various therapeutic techniques see Levitt, 1975). No therapeutic school, at present, has a comprehensive scientific theory on which its therapeutic system is based; this is no argument against the systems but it is simply due to a lack of knowledge about normal and abnormal development of motor control. It is interesting, however, to see that changes

in the concepts of motor control had their impact on therapeutic schemes. Initially treatment was directed towards improvement of muscle function, later it was directed towards the improvement of movement and at present towards the improvement of skills. Most schools stress the relevance of space, gravity, position, orientation and posture. (Bobath, 1965; Vojta, 1974; see Levitt, 1975)
Posture and postural reflexes are the corner-stone of the Bobath therapeutic system (Bobath, 1965, Bobath, 1971, Bobath and Bobath, 1966). These authors make a plea for a better knowledge of normal postural development.

1.4.2. Position and posture in neonatal care

Some newborns are too sick and weak to achieve a posture or to perform postural changes. Consequently, they remain for very long periods in the same configuration. If the care-giver does not regularly change the position of such newborns, then those rigid configurations may result in changes in the visco-elastic properties of the muscle and the tendons, so that structure and function of receptors are adversely influenced.

In the context of neonatal care it should be mentioned that posture and postural changes play a specific role in the optimalisation of breathing. Posture and postural changes result in regularly changing configurations of the lungs and their composing lobes, this favourises the bronchial drainage of the various segments of the tracheal-bronchial tree (see Dunn and Lewis, 1973). Furthermore, an adequate and changing thoracic expansion prevents identical lung segments from remaining in identical positions for too long a time and thus prevents alveolar collapse. Thus, if the amount of spontaneously occurring postural changes is too low the care-giver will have to substitute for those functions.
Finally, the head-posture and the head-body configuration are determining factors for the resistance and the flow in the upper airways, e.g. newborns in the defensive phase of respiratory difficulties are frequently observed to hyperextend the head, this seems an adequate compensatory mechanism.
A better knowledge of postural behaviour in normal newborns will increase the possibility of providing adequate substitute programmes for sick and weak newborns.

1.5. THE APPROACH OF THE PRESENT STUDY

An interest in the ontogeny of posture is not new, therefore previous studies, with their approach, will be briefly reviewed in this paragraph before discussing the approach of the present study. Schaltenbrand (1925), and Peiper (1956) in his book "Die Eigenart der kindlichen Hirntätigkeit" and Zador (1938) describe posture as reflexes and the ontogeny as an accumulation of reflexes. Those authors stress the relevance of the vestibular and neck-proprioceptive reflexes for the development of postural behaviour in the human. Their approach is based on the physiological studies on postural mechanisms in adult dogs, cats and rabbits of Magnus (1924), and Rademaker (1931).
And here the first problem in their approach is touched upon, namely the extrapolation from neurophysiological experiments in adult animals towards behaviour of human neonates.
In neurophysiology even the links between the findings on motor-control in cats, dogs and lower primates and the findings on motor-control in higher primates are still difficult to make (Granit, 1970, Evarts et al., 1971, Granit

and Burke, 1973).
Large differences exist in the structural and functional organisation of the supraspinal motor-control between species that show consistent differences in their daily life motor repertoire e.g. the differences in the cortico-spinal tract and its functional organisation in animals with and without finger grasping (Nijberg Hansen, 1966, Kuypers, 1973).
A second problem is the extrapolation from adults to infants. Since data on the ontogeny of motor control inside species are scarce.
In Rhesus monkeys there exists a very close relation between the development of the lateral descending system more specifically the direct cortico-motoneuron connections and the appearance of finger grasping (Kuypers, 1962, Lawrence and Hopkins, 1972, Kuypers, 1973).
As to the ontogeny of the medial descending spinal system (Kuypers, 1973), which would be relevant for the control of head, neck and body posture no ontogenetic structural-functional correlates are yet available.
The same holds true for the development of the sensory system in postural control. Ten Kate (1969) studied the vestibulo-ocular-reflex in the growing pike. The author was more interested in the biophysical characteristics of a growing receptor than in the the ontogeny of central nervous system functioning.
Schwartze and coworkers studied behavioural, physiological and structural aspects of the ontogeny of both vestibulo-ocular and vestibulo-spinal mechanisms in the rabbit. They studied the air-righting reflex and the eye movements on the one hand and the structural maturation of the vestibula, the vestibular nuclei, the oculo-motor nuclei and the eye muscles on the other hand. In the newborn rabbit the vestibulo-ocular and vestibulo-spinal systems are already quite mature both structurally and functionally but in the oculo-motor nuclei and in the eye-muscles the maturation is not yet finished, (Schönfelder and Schwartze, 1970 and 1975).
A third reason to be cautious with extrapolations is a pure methodological one. In classical neurophysiological experiments fragments of postural behaviour are intentionally isolated in such a way that reproducible measurements are feasible. In behaviour such fragments can from time to time be presumed but as such they are not available, e.g. the asymmetric tonic neck reflexes which are never rigidly observable in normal young infants (Vasella and Karlson, 1962, Beintema, 1968, Claverie et al., 1973 and Touwen, 1976). A similar problem is reflected in the difficulties that emerge when one tries to tie findings together from lesion or stimulation experiments with results from recordings of neuronal activity in awake and active animals; in classical neurophysiological experiments consistent temporal relations can be considered as functional relations; in the recent more complex experiments the interpretation of temporal relations between recorded neuronal activity and muscle activity as final evidence for functional relations is still much debated (Granit and Burke , 1973, Evarts, 1973).
Finally, recent advances in human neurophysiology, such as transcutaneous single unit recordings of peripheral nerve fibers (Vallbo, 1971), do not exclude that in a not too distant future it will be possible to study developmental patterns of alpha and gamma control.
First, however, a detailed knowledge of steady states in motor behaviour is required to reduce the scatter in the results and to enhance the chances for a meaningful interpretation.
From the arguments so far it becomes clear that the present study will not search for fragments of behaviour which recall neurophysiological reflexes but that neonatal postural behaviour will be described in the hope to derive categories of stable and biologically relevant postural behaviour.

Detailed descriptions of head, body and extremity positions in the newborn are available in the studies of the behaviourists such as : Pratt et al., (1930), Marquis (1933) and Wagner (1938). Those authors as pure behaviourists were not interested in the underlying neural mechanisms; their studies only describe what can be seen in the newborn and young infants and give no information about "how and why" it is achieved. The temporal aspects of behaviour are only scarcely documented in those studies.

Gesell and coworkers studied postural development in human infants; Gesell's theoretical position, however, is the maturation hypothesis; therefore those authors were primarily interested in the establishment of norms (Gesell and Ames, 1940, Gesell and Halverson, 1942, Gesell and Amatrude, 1947, Knobloch et al., 1966). Gesell and Amatruda (1947) mentioned and McGraw (1963) and Touwen (1976) stressed the inter- and intraindividual differences in the development of postural behaviour. Touwen (1976) considers this intra-individual variability as sign of neural integrity and the absence of variability as an alarm sign of dysfunction.

In the present study my concern will thus be more a careful description of behaviour than the establishment of norms. Daily life observations will be the take-off point for the present study; does the human newborn need postural control to perform his early functions better ? Or is neonatal behaviour in space fully determined by the care-giver ?

Newborns will be observed during wakefullness and sleep while they are placed in various positions or while they are carried by their care-giver. To study postural behaviour in sleeping infants may sound a contradiction to some readers. There are, however, two sound reasons for this approach : first a biological one, namely newborns spend 70-80 % of their time asleep, during which they demonstrate various motor phenomena and body postures.

A second reason is a methodological one; the study of the same phenomena in the the different behavioural states proved to be a useful strategy in the study of nervous system functioning in infancy (see Prechtl, 1974)

In the present study, an attempt will first be made to demonstrate that the neonate has already different modes of postural control. In a second series of observations and recordings the presumed postural control will be further tested by loading the system using well controlled positional changes, namely rocking experiments, and by studying how the newborn reacts to those controlled stimuli.

Finally, since posture and postural changes ultimately are the result of modulations in muscle activities, those muscle activities in relation to observed postural behaviour will be studied in the various behavioural states.

A better knowledge of the modulation of muscle activities in normal infants may be the start for an early detection and categorisation of abnormal infants.

Chapter 2

SUBJECTS

68 newborns were selected for this study. They were all born between 1.1.1969 and 1.12.1973 in the Department of Obstetrics, University Hospital, Groningen. Because hospital delivery in the Netherlands generally occurs on medical or social indication, the group had to be selected from a population that carries higher risk for obstetrical and neurological complications than the Dutch population in general. Therefore only newborns that fulfilled the following paediatric and neurological criteria were included :

2.1. PAEDIATRIC CRITERIA

All 68 newborns were normal full-terms i.e. 38 to 42 weeks of postmenstrual age. There was full agreement between the length of gestation determined according to the mother's history, the skin parameters and the neurological parameters. Methods to estimate the postmenstrual age were extensively reviewed by Casaer and Akiyama (1970, 1971).
The birthweights were between the 10th and 90th percentile of the Dutch newborn weight distribution (Kloosterman, 1969). This means that all infants studied were heavier than 2960 grams and lighter than 4070 grams. In one pilot study there was a normal full-term with a birth weight of 4560 g. Details about weight categories of the newborns in each subgroup of the study are mentioned in column 3 of table 2.1. As can be seen from Table 2.1 in all final subgroups the range of weights was even smaller (25th-90th percentiles or 3210-4070 g). This was indicated in the studies in which the infants were placed in specific environmental conditions such as the baby-seat, the rocking table or the head-holder to reduce the differences between the infants and their environmental conditions.

On the day of the neurological examination and on the day of the observation or recording none of the infants was jaundiced and all infants had stable or increasing weights.

2.2. NEUROLOGICAL CRITERIA

All infants had a normal neurological examination. This examination was performed according to the method described by Prechtl and Beintema (1964).

2.3. SEX

The sample of 68 newborns consists of 42 girls and 26 boys. The excess

TABLE 2.1.

Subject and methods

Group	Number	Weight Percentile	Age in days	Sex ♂	Sex ♀	Environmental conditions	Length of observations (hours)	Number and type of visual documentation	Number of Polygraphic recordings	Number of Special EMG studies	Positions
Postural behaviour in various positions											
A	3	25-90	0-16	2	1	at home	1-2	Photos - 1	-	-	variable + carrying
B	6	10-90	0-8	2	4	nursery	1-2	------	-	-	variable + carrying
C	3	10-90	5-8	0	3	climate room	2-4	video 2	3	-	supine
D(pilot)	5	10-90	5-8	4	1	climate room	4-6	video 3 photos 1	5	-	supine horizontal and supine sitting
D'(final)	6	25-90	5-7	3	3	climate room	6-8	------	6	-	supine horizontal and supine sitting
E(pilot)	5	25-90	4-5	1	4	climate room	4-6	photos 3	5	-	prone and supine
E'(final)	6	25-90	4-5	0	6	climate room	6-8	time-lapse photos 1 photos 4	6	-	prone and supine
A-E	34			12	22			15	25		
Postural reactions to imposed postional changes											
F	7	25-90	4-8	3	4	climate room	2-4	photos 1	7	-	transversal rocking
G	3	25-90	5-8	0	3	climate room	3-4	photos 3	3	-	longitudinal rocking
H(pilot)	4	25-90	5-8	2	2	climate room	2-6	photos 6	4	-	longitudinal rocking + spontaneous head-movements
H'(final)	6	25-90	4-8	3	3	climate room	3-4	photos 6	6	2	longitudinal rocking + sucking
F-H	20			8	12			16	20	2	
Postural behaviour and muscle activity in newborn infants											
I(pilot)	10	25-90	4-5	4	6	climate room	2-6	photos 5 time-lapse photos 1	10	10	variable + sucking
I'(final)	4	25-90	4-5	2	2	climate room	2-6	time-lapse photos 4	4	4	side position + sucking
I-I'	14			6	8			10	14	14	
Total n = 68				26	42			41	59	16	

Posture during sucking (n=12) identical newborns as groups H'-I' and one baby from group I.

in girls may be explained by the fact that, when in a neonatal population all newborns are neurologically examined the chance of having a normal neurological examination is higher for girls than for boys (Prechtl, 1968). Details about sex of the newborns in each subgroup of the study are listed in column 5 of table 2.1.

2.4. NEONATAL AGE

The newborns were studied between their 4th and 8th day of life. In some of the pilot studies (see column 4 of table 2.1) the infants were also studied beyond this age period.
In 1972, halfway through the data collection period the policy of the obstetrical ward was changed in so far that mothers and infants went home at day 6 instead of at day 8. This policy resulted in an overrepresentation of infants studied on days 6 and 7 in the first part of the study and in a overrepresentation of day 5 in the second part of the study.

2.5. GOALS OF THE STUDY, USE OF THE SAMPLE (see table 2.1.)

In a first group of infants, the largest group namely 34 out of 68 spontaneous postural behaviour without any stimulation was studied in newborns placed in the supine, the prone, the side or the sitting position.
In a second group of 20 newborns postural reactions during controlled positional changes were studied, namely during rocking along either a transverse axis or a longitudinal axis.
In a third group of 14 infants muscle activity in relation to postural behaviour in the various behavioural states was studied.
Finally, the posture during feeding was studied in 12 newborns.

Chapter 3

METHODOLOGY

3.1. ENVIRONMENTAL CONDITIONS

3.1.1. At Home

As the starting-point of the present study on postural behaviour and postural control a series of newborns were observed at home. These infants were each observed on five occasions in their first sixteen days of life. Their homes were centrally heated, the room temperature was between 18°C and 22°C.

3.1.2. The nursery

The behavioural observations at home were supplemented by 18 observations on six newborns in the nursery of the Department of Obstetrics. Both at home and in the nursery the babies were clothed and two mothers and all the nurses wrapped the newborns in a soft blanket during feeding or carrying. The normal newborns in Groningen were nursed in a large ward, with 30 cribs. The ward was rather bright and sunny, the temperature about 22°C. A small examination room adjacent to this ward could be heated in five minutes to a temperature of 28°C. From 1974 onwards the babies are nursed in a rooming-in system.

3.1.3. The climate room

The largest group of infants (59 out of 68) were brought on the day of observation and recording from the nursery of the Department of Obstetrics to the climate room in the Department of Developmental Neurology. The climate room had a constant temperature of 30°C and a constant relative humidity of 50%. Temperature and humidity were continuously monitored. In this warm environment the newborns wore only a diaper and some of them a sleeve-less shirt. Sound and light were kept constant. Depending on the topic under study the newborns were placed on a soft board, in a crib, in a baby-seat or on a soft platform that was part of a rocking table which allowed transversal or longitudinal rocking of the baby. Finally during one part of the study the baby's head rested in a head-holder enabling head movements along a longitudinal axis.
The climate room was separated by a thermopan glass wall from the equipment room. Through this glass wall the babies could be observed and photos and films could be made. For the video-tape recordings the camera was inside the climate room. During all experiments in which positional changes were used, one silent observer was immediately close to the newborn, so that the observer could always interfere or stop the experiment.

3.2. TIME OF THE DAY AND TIME SINCE THE LAST FEEDING

Observations and recordings started in the morning. The majority of the newborns was brought into the climate room shortly before their second feeding (9H or 10H). After their preparation the observation and recording started with the feeding.
A smaller group of infants, whose mothers preferred to feed their baby either by breast or by formula feeding, came after the nine or ten o'clock feeding to the climate room. Factors such as time of the day and time after the last feeding, which are known to influence neonatal behaviour, should be strictly controlled in neonatal behavioural and physiological research.

3.3. LENGTH OF THE OBSERVATIONS AND THE RECORDINGS

The wish of the researcher was to observe and to record as long as possible The actual decision, however, was made by the mother. Several mothers did not dislike the idea that their baby was gone for a few hours and for one feeding (2-4h session). An absence of their newborn for the "whole day" (4-8h session) was considered as being too long by a considerable group of mothers.

The average length of all experiments was 4 1/4 hours (see table 2.1 column 7). Those experiments from which conclusions should be derived as to the effect of orientation on behavioural state cycling, on the amount of movements and on respiratory rate lasted at least six hours. In those subgroups each newborn was his own control and the time of a positional change coincided with the midrecording feeding.

3.4. BEHAVIOURAL OBSERVATIONS

In this and the following paragraph a global description of the type of material collected will be given : namely behavioural descriptions with or without visual documentation and polygraphic recordings of physiological signals. Details of this methodology will be reported in each part of the study close to the results to enhance the readability.

3.4.1. Descriptive notes

The observed postural behaviour was laid down in descriptive notes. A dictaphone proved to be helpful since its use enabled a more continuous and close observation.
At home a series of photos of typical postures were made for documentation and illustration. In the laboratory the approach was similar. During the whole project (59 observations) descriptive notes were written on the bottom of the polygraphic paper-write-out on which the physiological signals and a time marker were recorded.

3.4.2. Video-Recordings

Five observations were recorded on video-tape. The camera was placed at the baby's foot-end under an angle of 45° with the horizontal and the

vertical plane so that an estimate of movements in a horizontal and vertical plane was possible.
The video-equipment consisted of : a camera with a zoom-lens, a camera control unit, a syncro-pulse-generator, a video-recorder, with 2 inch wide video tape and a video-monitor.
Play-back for visual analysis took place, at normal, slow motion or picture by picture transport. By repeated analysis of the same material the observers became more quickly familiar with new behavioural categories for example the postural behaviour of newborns while lying in prone or while sitting in a baby-seat.

Once from previous observations and video-tape analyses behavioural categories were so well identified that they could be recognized by each observer when they appeared again, these categories were coded and then the codes were written on the paper write out. The most frequently used behavioural items with their codes are listed in table 3.2 and their definitions in table 3.1.

TABLE 3.1.

Definitions of behavioural items

Jerk or Startle : a sudden short lasting movement involving head, trunk, arms and legs
Periodic Respiration : a periodically occurring change in the depth of breathing i.e. an amplitude modulation of a regular or an irregular ongoing breathing pattern.
Sigh : a sudden deep breath occurring during regular or irregular breathing.
Stretch : a gross-body movement during which head and trunk are extended and during which rather slow flexion and extention movements of the extremities occur.
Twitch : a sudden short lasting observable contraction of a muscle or a muscle group, resulting in isolated movements of an extremity, part of an extremity or in facial grimacing.

TABLE 3.2.

Behavioural items and their codes

B.	= Blink	H/Mvt.	= Head Movement
E.M.	= Eye Movement	I.R.	= Irregular Respiration
Ext.	= Extension	J.	= Jerk or Startle
Eo/c	= Eyes open-closed	L.	= Left
Flex.	= Flexion	Mvt.	= Movement
Fr.	= Frowning	Mo.	= Mouthing
Fus.	= Fussing	P.R.	= Periodic Respiration
Grim.	= Grimacing	REM	= Rapid Eye Movement
Ha/F	= Hand-Face contact	R.	= Right
Ha/M	= Hand-Mouth contact	R.R.	= Regular Respiration
Hic.	= Hiccup	S.	= Sigh
Hic.+Voc.	= Hiccup + Vocalization	SEM	= Slow Eye Movement
H.L.	= Head-lift	Smile	= Smile
H.L.±	= a not successful effort to lift the head	Str.	= Stretch
H.L.+	= a head-lift lasting shorter than 2 seconds	Sz.	= Sneeze
		Tw.	= Twitch
H.L.++	= a head-lift lasting for 2 seconds or longer	Voc.	= Vocalization
		Y.	= Yawn

3.4.3. Photography and time-lapse photography

The video-recordings and analyses were optimal for initial explorations. They asked however, more investment of manpower and equipment than there was available for this project. Therefore, during the majority of the recordings (30 out of 59) photos were made each time the baby's posture changed.
However, since small and especially gradual changes in posture stayed unnoticed, it was decided to use time-lapse photography in the last part of the study, in which the focus was on the relation between observed posture and muscle activities. A 16 mm Bolex camera was used. The film transport and exposition devices were brought under control of a camera control unit. This unit using the output of the time-code generator enabled us to start at any desired pre-selected time, at any desired pre-selected time-lapse, a one-hot or continuous cinematography. In this study a time-lapse of 5 or 10 seconds was used, and one-shot photographic documentation of the whole 3 to 6 hours recordings were made. During feedings some continuous cinematography was performed.

In conclusion, during the study a continuous effort was made to refine the descriptions and the visual documentation material. The time-lapse photography as a parallel to the continuous monitoring of physiological signals (see next paragraph 3.5) was a good compromise between detailed event registration and a document that would permit the analysis of trends or gradual phenomena.
It should be clear, however, that these technical gadgets are only helps to and never replacements for the observers. At least two observers were present, one observed the infant and made notes or dictated comments, the other supervised the equipment; each twenty minutes tasks were changed. During stimulation experiments the rotation involved a minimum of three observers, the third closely observed the baby and its comfort.

3.5. POLYGRAPHIC RECORDINGS AND THEIR ANALYSES

A polygraphic recording is a simultaneous registration of various physiological signals, which may have different signal and information content. Details about this polygraphic technique and its standard way of analysis have been extensively discussed elsewhere (Prechtl et al. 1968; Prechtl, 1968; Prechtl et al., 1969).
Since this study focusses on motor-output i.e. is about posture, postural changes and movements and their electromyographical correlates, an effort has been made to improve the surface electromyography and the position recordings. Some new methods for signal analysis have been developed and applied. These methodological aspects will be discussed in Chapter 5 close to specific problems and results.
In this paragraph an overall picture is drawn of the type of signals, the "why" and "how" they were recorded, and to what kind of results they led.
One of the fundamental aspects of the functional organization of the newborn's behaviour is the cyclic pattern of sleep and wakefulness, the behavioural state cycles. All physiological variables so far studied : blood-pressure, oxygen consumption, reflexes or electroencephalograms, show different values or properties according to the behavioural state of the infant. Therefore, in the present study of unknown behavioural and physiological aspects, it was decided to continuously monitor several state related parameters. Furthermore, the polygraphic recording of a standard set of physiological parameters beside the one parameter specifically under

study proved to be a good research strategy to avoid that the drawing of too simplistic cause-effect relations and conclusions. In the present study a respiratory signal, an electrocardiogram, a cardiotachogram, electrooculograms, two or four electroencephalograms, electromyograms and a time code were recorded.

3.5.1. The recording equipment

The equipment consisted of :
- an 18 channel Offner-Beckmann Dynograph Type R. The on-line paper-write-out ran at a speed of 6 mm per second
- 13 of the 16 signals, selected for analogue storage, were recorded on a 14 channel 1 inch analogue tape by means of an instrumentation tape recorder (Ampex FR 1800 or Bell and Howell type VR 3700 B)
- the standard computer analyses were performed after analogue to digital conversion and digital filtering on a PDP9 and PDP15 computer
- for signal monitoring and artefact detection during the recording and for off-line analogue analyses a double-beam storage oscilloscope, Tektronix type 564B, was available.
- a pin-board was built, in which inputs and outputs of all equipment formed an interconnection matrix. This facility allowed that any desired connection between different items of equipment could be made rapidly and simply.

3.5.2. The recording technique

Respiration

Newborn infants are obligate nose breathers. Therefore a thermistor mounted on a plastic holder was taped to the bridge of the nose in such a manner that it lied over the external opening of the nostril. The thermistor heats during expiration and cools during inspiration because there is a difference in temperature between the air in the baby's lung and in the room. A varying temperature gives a varying resistance which was transformed in a varying voltage.
To avoid errors induced by air streams induced by the rocking movements, a small open cylinder was built around the sensitive prove, the longitudinal axis of the cylinder lying in the breathing flow.
As the respiratory rate is slow, an adequate recording can only be obtained when amplifiers with a long time constant are employed, such as 1.0 and 3.0 sec.

This voltage over time, the respiration signal was analysed after analogue to digital conversion into respiratory rate and respiratory-rate regularity by means of a respiratory interval-time analysis over the consecutive 3 minutes epochs of the entire records.

Electrocardiogram and cardiotachogram

Two Grass silver disc electrodes filled with standard electrode paste, and later in the study two silver-silverchloride-platinium-powder pellets (I.V.M. CALIFORNIA) mounted in electrode cups designed in our Department (see chapter 5), were the pick-ups for the EKG signal. The electrodes were attached with adhesive-tape, one on the forehead and the other on the thorax between the left anterior costal border and the left nipple. These locations together with the use of a short time constant (0.03 sec) gave

a prominent R-wave sufficient to trigger the Offner Cardiotachometer Unit type 985.
The cardiotachometer provides a write out of the interval-time between two successive R-peaks as an amplitude, which can be callibrated to reflect rate per minute.
This signal is very helpful for the visual analysis of the polygram, but was not further used for computer analysis.

Computer analysis of the heart rate and its regularity were done by means of the R-wave interval-time analysis over the consecutive 3 minute-epochs of the entire records.

Electroencephalograms

This project is not an electroencephalographic study in the newborn. The EEGs were recorded as one of the "behavioural state"- related physiological concomitants.
Furthermore, the unstimulated infants by whom spontaneous behaviour was studied in prone, supine or side position were also used as normal controls for another project on electroencephalography and its information content in normal as compared to abnormal infants. This last reason is a pragmatic but a valid one.
Details about the EEG recording technique, its computer analysis and results related to the EEGs are published elsewhere (Vos, 1975 and Vos et al. 1976).

Electro-oculograms

Rapid eye movements are a characteristic phenomenon in one of the two sleep "states" in the newborn. Eye movements were studied as the output resulting from vestibular and proprioceptive inputs. Therefore, in all our recordings the eye movements were registrated by means of electro-oculography. The eye is a bipole due to the cornea-retinal potential difference. By placing electrodes adjacent to the eye ball, eye movements can be recorded as changes in voltage over time.
For the horizontal eye movements a bipolar derivation from an electrode on the outer canthus and an electrode on the nosebridge and for vertical eye movements a bipolar derivation from an electrode on the upper and lower margin of the orbit were obtained. Small silver disc electrodes filled with electrode paste were fixed with tape. If not otherwise stated the EOGs were recorded from the right eye. The time constants used were 1.0 and 3.0 seconds since we were interested in slow as well as in rapid eye movements. Off-line the number of rapid eye movements per time (e.g. 3 minutes) were counted.

Electromyography

Surface electromyography was used since this technique was considered appropriate for the actual questions to study and also since it was agreed upon with the parents not to prick their infants. In all recordings, except for the last fourteen, the procedure went as follows : the skin electrodes consisted of two silver rods, 2.4 mm diameter, mounted at a distance of 1.0 cm. in a perspex plate, 13 x 30 x 3 mm. These electrodes covered with electrode paste were fixed with tape over the appropriate muscle bulk. A very short time-constant was used (0.03 seconds). The EMG recorded in this way permits a visual analysis of movement correlates; rough differentiation in short and long lasting activities is possible.

During several experiments some EMG signals were integrated by the Offner EMG Integrator type 9852.

Earthing

In the first part of the study infants were grounded, i.e. they were connected to the common of the equipment.
Later in the project a full separation between the baby with its pick-up electrodes and their initial amplifiers on one side, and all the rest of the equipment on the other side was developed. This last procedure is absolutely the safest and thus the best one.

Time

A paper-write-out of physiological signals together with observational notes, an analogue tape-recording of physiological signals, and time-lapse photography or video-tape recordings or photos, those are the three forms in which our observations were laid down for off-line analysis. It is obvious that an accurate synchronisation between these data-records is mandatory.
As the project went on the following form of organization was established; a time-code generator, type Systron Donner Model 8350, generated a time code of the IRIG-B standard.
This time-code was written out in a minute, a 10 seconds and a one second mark on the paper-write-outs. It was also stored by means of a DC channel on the analogue tape. It was used as the time clock for the camera-control unit and by an extra display of this time-code close to the infant, the time at which each photo or video-picture was made, was present on the photo. The presence of the time-code on the analogue tape is a must for all off-line analogue digital analyses.

3.5.3. Type of results

As a guide into the following chapters a short account of the type of results is reported.

The polygram

The polygram is the on-line write-out of the physiological signals plus behavioural notes and the behavioural codes. By visual analysis of this document a detailed qualitative description according to a standardized procedure and the following quantitative data were generated :
duration of the individual behavioural states, percentage of total time spent in each state, total duration of gross-body movements as percentage of total recording time and a similar figure per individual behavioural state.
Further, depending on the question under study, frequency or interval distributions of episodic events such as startles, gross-body movements and sighs were determined.
A further step in the visual analysis was to describe in detail particular signals such as EMGs and position, this in relation with the photographic documentations and descriptions of motor behaviour.

Playbacks

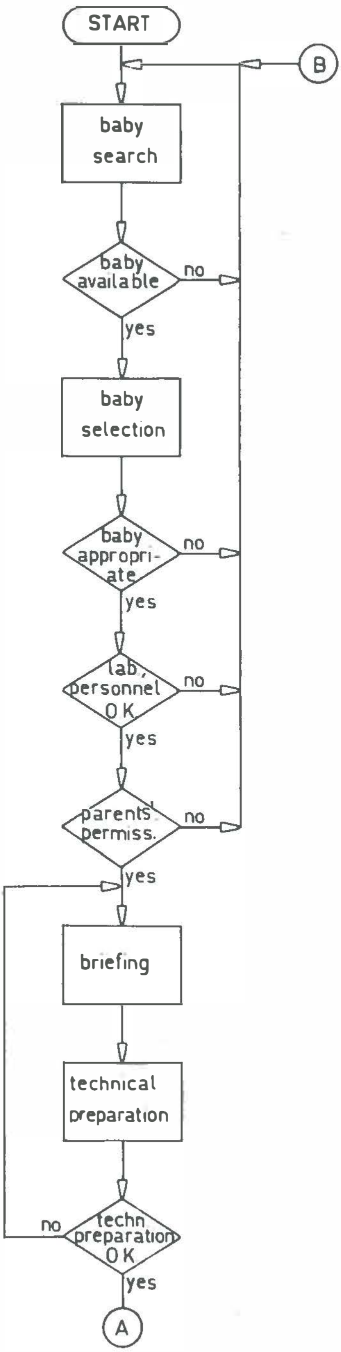
After each recording a 16 times compressed playback was made, the instrumentation recorder reproduced the signals at an eight time higher speed

than the recording-speed (15 inch per second instead of 1 7/8 inch per second), the paper ran 3 mm per second instead of 6 mm per second. From such a playback a general overview of the data collected could be quickly obtained and major technical problems and artefacts could be detected and earmarked for all further off-line analyses.
Play-backs of stored signals, and play-backs of a combination of some stored signals and some analogue analysed signals were made at various speeds according to the time basis optimal for the question under study. This was possible thanks to the large range of recording and reproducing speeds of the instrumentation recorder ($1^{7/8}$, $3^{3/4}$, $7^{1/2}$, 15, 30, 60 and 120 inch per second) and to a large range of paper transport speeds (1.5, 3,0, 6,0, 15, 30, 60 and 150 mm per second or per minute).

Digital data

Of all recordings made on unstimulated babies and of some recordings of the stimulation-experiments the following digital computer output was obtained of all consecutive 3 minute-epochs of the entire record;
the 50 percentiles and the interquartile ranges of the histograms of interval times of respiration and heart-beat and the corresponding respiratory and heart-beat frequencies,
the number of rapid eye movements per 3 minutes,
the mean square voltage, a measure for the averaged amplitude, of the EEG.
With these values again sequential plots can be made, and these values can be submitted to various sorts of statistical computations.

3.6. ACTUAL PROCEDURE "FROM BABY TO EXPERIMENT"



"A second look at the Methodology" could be the subtitle of this paragraph. Starting point is a healthy newborn who remains with his mother a few days (3-8) in an obstetrical department; goal is a study on phenomena in normal infants, in this case : postural behaviour and its mechanisms. Studying these phenomena in normal infants is felt necessary for a better unterstanding of pathological phenomena. In this paragraph the various steps in this procedure are described, (see flow-chart).

Baby search

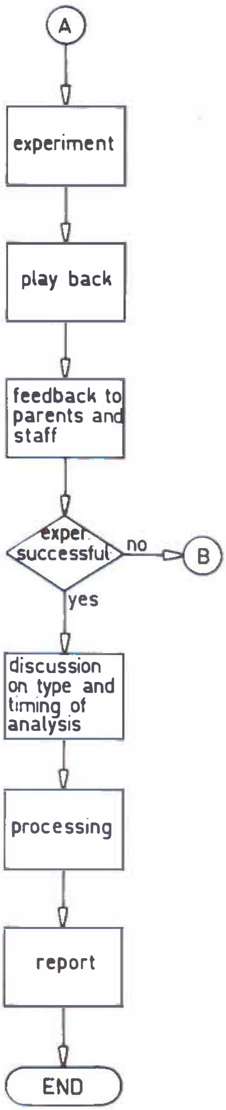
The researchers involved in this study assisted in a neonatal neurological screening project of all newborns born in the University Hospital in Groningen; they were consultants for neonatal and developmental neurology. Medical and nursery staff must be convinced of the relevance of the study, this required periodical briefings.

Baby selection

If a baby was considered neurologically normal then together with the resident in charge of this baby, it was decided if this baby was appropriate for the study. The personality and history of the parents, and expecially if previous infants had been ill or had died, are of utmost importance for this decision. Parents may consider the experiment as a camouflaged extra detailed examination of the new baby.
Cancelling of the experiment should be avoided since this confuses parents and nurses; therefore, before talking to the parents it is necessary to check if laboratory personnel and technical requirements are such that the experiment can take place.

Parents' permission

The parents were told :
1. Your baby is in perfect health.
2. We think it is important to study normal infants in order to help abnormal infants better.
3. We would like to observe your baby and to record simultaneously various signals with pick-ups taped to the skin but without any needle or device penetrating the skin.



In broad lines the procedure was described. The possibility of a short recording (lasting 4 hours) or a longer one i.e. a two feed-interval-recording (lasting 6 to 8 hours) was discussed. The parents had time to discuss their decision with each other.

Briefing

After the parents'permission was obtained, researchers and technicians sat together to discuss the type of experiment, the task division before, during and after the experiment; since such discussions during the experiment should be avoided.

Technical preparations

Everything that can be done without the baby's presence should be ready before he arrives. A count-down or a check-list "from electrode to analogue tape", the preparation of the visual documentation and the calibrations should be ready on the evening before the experiment.

Experiment

At least two observers were present, one observing the infant, and one the recording equipment. For visual documentation a third person taking photos or supervising filmcamera or video equipment is mandatory. During stimulation procedures one observer was immediately next to the baby and he had the highest priority to interrupt the course of the experiment.

Play-back

Immediately after the experiment a play back was written out. Major technical problems and artefacts are easier to interpret just after a recording.

Feed-back to staff and parents

One of the researchers and a technician brought the baby back to the nurse in charge and they reported to her and to the mother on the course of the experiment, on the amount of time the baby was awake or asleep, on how he took his feeding and on other possibly relevant observations. The parents were once more thanked for their cooperation and an opportunity for eventual further questioning was offered during the following days.

Experiment successful ? Discussion on type and timing of the analyses.

It became obvious during the present study that type and timing of the analyses should be planned before or at least soon after the experiment. If not, the danger exists that in an initial phase a too large data-collection is made before one realizes some pitfalls in the analyses, that may have implications for the methods of data collection in subsequent experiments.

Data processing and report

All visual analyses and calculations made on data derived from these visual analyses were summarized on the polygram-report. A flow-sheet to guide the analogue tape through the various analogue and digital analyses proved to be useful.

Chapter 4

POSTURAL BEHAVIOUR IN NEWBORN INFANTS

In this section postural behaviour of newborns, observed between their 4th and 8th day of neonatal life, will be qualitatively described. An attempt will be made to answer the following question : is there any evidence from the study of neonatal behaviour that the newborn reacts against gravity and that he reacts differently according to his position in space ? If so this would mean that a newborn has postural mechanisms and that it is worthwile to study these mechanisms more accurately, i.e. with more refined descriptions and with quantitative methods.

The following account is derived from 15 observations on 3 babies at home, from 18 observations on 6 babies in the nursery and from 39 observations on 39 babies in the climate room, i.e. from all observations without imposed positional changes (for details see Table 2.1.).
Observations were laid down in descriptive notes and could be reanalysed on photographs, on some videotapes and on time-lapse photographies.
The report starts with a description of newborns lying in their cribs, awake, falling asleep, asleep and waking up. Then follows a description of newborns carried by their mothers or nurses, and finally some date on sucking newborns will be given.
After describing postures and postural behaviour a short note on the relationship between respiration and posture will be made.

4.1. NEWBORNS LYING IN THEIR CRIBS

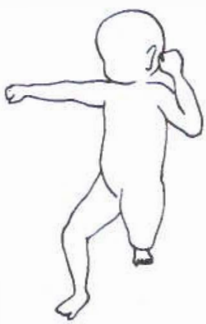
In his cradle the newborn was placed in supine, in prone or in a side position. The baby could change this position actively into a partial side-supine or a partial side-prone position.

4.1.1. The awake newborn in the supine position

The awake non-moving newborn (state 3), with his eyes open and glancing around, was rarely lying with his face centered in the midline, it was mostly turned partially to a side, frequently to the right side, the cheek was not in contact with the supporting surface. The arms were frequently adducted in the shoulders, somewhat endorotated, they were flexed in the elbows so that the forearms and hands were resting on, or were in

contact with the trunk. The legs were adducted in the hips, they were flexed in the hips and in the knees. Sometimes they crossed over under the knees or they were flexed in parallel in hips and knees so that the soles of the feet were standing, close to the buttocks, flat on surface of the bed. For this posture, especially for the head position, antigravity tone in the muscles should be assumed.

Beintema (1968) demonstrated that the flexed postures are more frequently observed in the first neonatal days and that after the 5th day of life a gradual increase of extension-postures and movements is seen. The semi-extended or semi-flexed legs are then resting more on the heels or the external side of the feet.
A smaller group of newborns had quite a different posture in state 3. The arms were abducted and exorotated in the shoulders, they were flexed at the elbows so that the hands were symmetrically next to the head ; also here some antigravity activity could be presumed since the forearms and hands were frequently observed to be a few millimeters above the bedsurface. Also for the legs there exists an abduction posture ; the legs were abducted and exorotated in the hips, mostly with semi-extension in the knees and with the heels resting on the bed. It is interesting to note that newborns with an adduction posture in state 3 showed more adduction movements in state 4 and newborns with abduction postures showed frequently abduction movements. The abduction-extension movements in the legs were very peculiar in this group of normal full-terms.
Four babies showed them very clearly and then also consistently during the whole observation period. These newborns were born in vertex presentation and had no signs of hip dysfunction.



Beside these more symmetrical postures, frequently asymmetrical postures were observed. The arm and leg of the face side were more extended, whereas the arm and leg of the occiput side were more flexed. The fingers and toes of the face side were more extended or semi-extended, the toes and fingers of the occiput side were more flexed and fisted. Each newborn showed such postures but none of them showed them rigidly. The variation in the degrees of flexion and extension was variable between babies and in the same baby at different times. The asymmetric postures were easily interrup-

ted by ongoing movements, especially by hand-face and hand-mouth contacts. This finding on the so called "spontaneous asymmetric tonic neck postures" is in full agreement with the findings of previous studies (Gesell and Halverson, 1942, and Touwen, 1976) : in normal full-term newborns the asymmetric tonic neck posture is frequently observed feature but never a rigid phenomenon.

The awake newborn in supine made frequently rather uncoordinated looking movements, many of them were strong enough to kick an extremity into the air. These movements resulted in mostly small but unpredictable changes in position. Other movements were more coordinated patterns and they resulted in more predictable postures. Two of the more stereotyped ones were hand-face and hand-mouth contact. Mostly the hand was brought closer to the face and the face turned closer to the hand, the fine adaptation of the two resulted from small head movements. If successful the baby started non-nutritive sucking and if he was hungry and awake a typical sucking posture followed (see paragraph 4.3.). For detailed descriptions on hand-face and hand-mouth contact see Gesell and Halversson (1942).

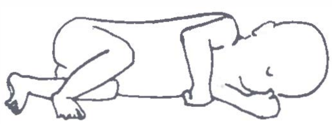
Newborns, a few days, old could be very responsive to sound and light stimuli or to stimuli combining the two qualities. They stopped moving, there was an overall freezing of the posture; only a few newborns showed eye fixation and eye following.

Locomotion was never efficient in supine position. Only when the hips and legs were partly tilted to the face side, push like leg movements could turn the baby's body around the position of his head and thus change the initial position in the crib. On several occasions newborns placed in supine changed during the observations into a supine-side or a supine-partly side-position. The crucial moment in the turning form supine to side was the tilting of the pelvis. Various strategies were used to arrive at this change, two types of total body movements were frequently observed : firstly, an overall flexion movement; the head flexed in the neck, the arms adducted and flexed, the legs strongly adducted and flexed in hips and knees, there was an overall rounding of the back, and the baby sometimes rolled over to the side. After the movement, during relaxation, either the baby passively rolled further into a side or back into a supine

position, or he stayed in a partial side position.
The other movement was an extension movement ; the head was extended in the neck, the arms were extended and adducted taking support besides the body, the legs were flexed in the hips and briskly extended in the knees. By this extension-sway of the legs the pelvis and frequently the whole body were flipped over to one side and after relaxation the newborn ended up in a comfortable side-resting posture.
Out of this movement also a very unstable posture could result. The face and shoulders were facing one side, the hips and legs were facing the other side. Such a twisted posture lasted never long. New total body movements occured until a certain degree of alignment between face, shoulder and hips was achieved. This alignment is a additional argument for the presence of some form of postural mechanism.

4.1.2. The awake newborn in the side position

The full side position made the impression of being a comfortable resting position. The face was resting in contact with the bed, the baby was lying on his shoulder and even on the ventral part of the arm. The trunk, the hips and the legs were aligned with the face. In this posture the underlying arm was flexed or semiflexed and the underlying leg was semiflexed or extended, the upperlying leg was frequently more flexed than the underlying one. At several occasions the upperlying leg was observed in a typical antigravity posture. The leg was somewhat flexed, in the hip and in the knee, the footsole was standing flat on the bed ; at the transition to sleep, this "standing" leg gently slided away.

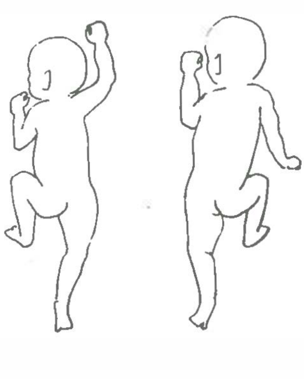


In the side posture the hands were very close to the face and thus hand-mouth contact and sometimes non-nutritive sucking were observed. Head-turns upwards, bringing the face to the midline, resulted in a roll over in the supine position when they were associated with strong total body movements. Head-turns downwards were incidentally seen, and then only in the awake states. They never resulted in a changing over into the prone position since the body was hooked by the underlying arm. Head-lifts lasting for a maximum of one second were seen in actively moving newborns in the side position, the face stayed more or less parallel to the bed during such movements. There was no real locomotion, changes of the body position in relation to the head position resulted from push-like leg movements.

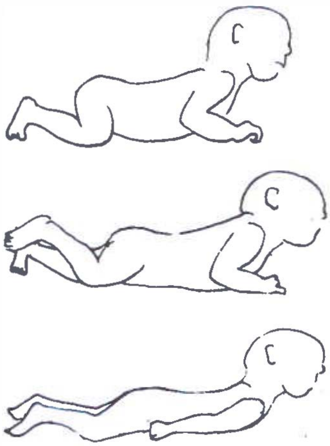
In the partial side position the face was not in full contact with the bed, the baby was not resting on the ventral side of shoulder and arm but on the dorsal side. Part of the back touched the bed, and the hips and legs were sometimes not fully tilted to the face side. This posture could be a moment of transition in the sequence of movements around the unstable twisted posture discussed earlier. But in other babies this posture was seen over a longer time and the baby returned to it after each movement. At the transition to sleep, however, this posture frequently disappeared, the baby rolled backwards into a full supine position.

4.1.3. The awake newborn in the prone position

In prone the quiet awake baby (state 3) showed an overall flexion and adduction posture. The cheek was in contact with the bed surface. The arms were flexed close to the body, the hands were close to the head, the legs were adducted and flexed in hips and knees, partially underneath the abdomen, so the buttocks were up in the air and the back was somewhat rounded. This picture was frequently seen in state 3 but it was not mandatory. Babies who showed abduction posture in supine had also less adducted arm and leg attitudes in prone. The difference could be described most easily when looking from above. In the "adducted" baby one saw mainly the head and the back, the extremities were barely visible outside this contour.
In the "abducted" baby the arms and legs were easily visible beside the body, the buttocks were not so far up in the air and the back was less rounded.



Besides those symmetrical postures frequently asymmetrical postures were observed in prone. The asymmetric tonic neck posture was not so obvious in prone. Hand-face and hand-mouth contacts resulted in a flexed head, arm, trunk and leg posture at the face side. So the face-side extremities were more flexed than the occiput-side ones, this was the opposite of what would be expected as an asymmetric tonic neck posture.



In other periods with crawling movements or with attempts to do so, a crossed-flexion and crossed-extension posture was seen.

Active awake newborns (state 4 and 5) showed head-lifts, side to side head movements and crawling. These were well coordinated postural programmes; the last one, crawling, resulted in locomotion.
Head-lifts were always total body movements. Arms and legs could be partially underneath the body and then it looked as if the baby pushed off on hands and knees. Arms could be flexed and legs extended and then head-lifts looked associated with push-like feet movements. Arms and legs could be extended and then head-lifting resulted from a total body arching, a short opisthotonus-like movement. This last type of head-lift was seen in state 5, when the baby was crying. Mostly a head-lift started with the face lying to the side, then the face stayed so during the head-lifting. Only during long lasting (2-5 seconds) head lifts or in a series of head-lifts the nose was brought to the midline.
Side to side movements of the head were observed in active awake newborns. Such movements and series of such sequences were especially seen when the baby was hungry. When they resulted in a good hand-mouth contact the newborns started sucking and then an overall increase of the adduction and flexion in the upper extremities and of the adduction and flexion or abduction and extension in the legs was observed. Side to side movements have been studied in detail by Prechtl and Schleid (1950-1951).
The developmental course in the first 10 days of head-lifting and side to side movements was studied in detail by Beintema (1968), he concluded that both head-lifting and side to side movements were rarely present on the first day of life, that there was a clear-cut increase during the whole neonatal period with a significant increase after the 5th day of life.

After a two to four hours lasting observation in prone, the newborn was never in the same place, there was always locomotion. Locomotion by crawling movements was seen when there were periods of active awake behaviour lasting several minutes. Stirnimann (1938) and Beintema (1968) demonstrated that the amount of crawling had a steep increase after the 5th day of life. Locomotion, however, could also result from more or less symmetrical flexion and exten-

sion movements of the legs, the knees being the most efficient supports in these push-forward movements. At several occasions newborns grasped their underlying sheet and pulled it downwards ; this interesting activity seemed not to be efficient for locomotion.
After such strong leg movements together with head lifting it could happen that the hips were tilted and that the legs, hips and trunk faced in the same direction as the nose.
Such partial prone-side positioning did not end into side position due to the flexed occiput-side arm. Partial prone-side positions were rare in the awake newborn.

Summarizing remarks on posture and postural behaviour in awake newborns

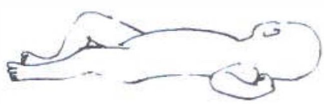
Awake newborns had an active posture, they did show postural behaviour.
During postural behaviour antigravity muscle activity was required. This was obvious at the onset of long lasting stable postures, but afterwards it was unclear if such postures still required muscle activity or if they were the result of visco-elastic properties.
Awake newborns had a different postural behaviour according to their orientation. Head-lifts occurred frequently in prone, exceptionally in the side position and never in supine.
Awake newborns did tend to align head and body. Twisted postures such as prone-side, supine-side were exceptional during the awake states.
Finally, already in the newborn types of movement and types of posture seemed tightly linked. "Posture is the shadow of movements" Sherrington (1947).

4.1.4. Fading away of the active posture while falling asleep

Close observation of newborns falling asleep may bring part of the answer to the question: is the stable posture observed in the awake states the result of an active motor control or merely of the visco-elastic properties of the tissues ?
The onset of sleep was arbitrarily defined as the moment in which the baby closed his eyes. Falling asleep could be gradual. Occasionally,however, newborns first made

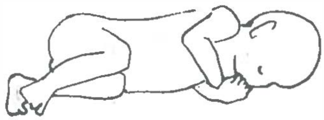
a movement that resulted in a more comfortable resting posture before falling asleep; at other occasions there was an epoch lasting 5 to 10 minutes during which the eyes were alternatively open and closed; during which the eyes could be half closed before they finally remained closed. This period of transition is sometimes called drowsiness.

In the supine position the face, which in the awake baby was not in full contact with the bed-surface, slided to the side while the newborn was falling asleep. The arms, when not in contact with the bed-surface or when lying on the thorax, gently slided downwards to a fully supported position. The legs, especially when they were standing in adduction and flexion, glided into abduction and exorotation. The fingers, frequently fisted while awake, opened to end up in semiflexed position. This in contrast to the toes which could be actively extended while awake; they tended to a more neutral flexed posture while asleep.



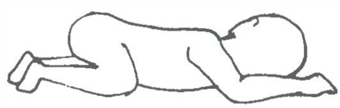
Babies, keeping their arms in an active abduction-flexion posture while awake, ended up in an abducted, exorotated and flexed arm posture while asleep. In this posture the dorsal surfaces of upper and lower arm were in full contact with the bed-surface. This posture was studied in detail by Drexler and Wengraf (1959). With Röntgen material they could show that in the newborns, in contrast to the adult, the resting position of the arms at the shoulder joint is an exorotated instead of an endorotated one. This disappearance of "active posture" could be gradual or sudden depending on the initial position, on the friction characteristics between skin and clothes, and perhaps on differences in motor control mechanisms. By "sudden" is meant the phenomenon of arms or legs just falling or quickly gliding down onto the bed. At such occasions the arms showed flexion-responses, the legs adduction-responses, and frequently startles occurred; then the baby sometimes briefly awoke, and occasionally he cried or vocalised. Sometimes no change at all was seen in the babies' posture when they closed their eyes. In such instances the disappearance of an active posture was observed after subsequent body movements during sleep.

In the partly side position, when face, shoulders and hips were not aligned, often during the transition the baby rolled backwards into a full supine position.



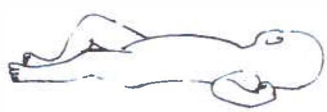
In the side position changes in posture from the awake state into sleep were minimal. The face was and remained in contact with the bed. It was hard to detect any change when the upperlying arm was semiflexed and resting on the body, and when the upperlying leg had a good support from the underlying leg and the bed. The observed minimal changes were : a gentle rolling of the shoulder to a more forward position, a change in arm flexion or in hand fisting, and a small change in the dorsiflexion of the foot and in the extension of the toes. At other occasions however, when during the transition to sleep the upperlying leg in the awake newborn was flexed and adducted with the foot standing on the bed-surface, the upper leg glided downwards until it reached the underlying one. When the arm was not well supported by the body, it glided forwards into a semiflexed arm posture. Occasionally it glided backwards behind the baby in a strange exo- or endorotated twisted position. This frequently resulted in a series of gross body movements in the subsequent sleep state.

In the prone position the changes in posture at the moment of closing the eyes were also hard to detect : a small change in head position, so that the cheek became in closer contact with the underlying sheet, small changes in arm and leg position that could be described as a slipping away of the extremities from underneath or from close to the body to a somewhat more abducted position. In prone the disappearance of an "active posture" was suggested strongly by the frequently made observation of a decrease in the curvature of the rounded back. In prone, as in the other positions, the fading away of the active posture often made the impression of being stepwise phenomenon, in such a way that the newborn ended up in a less active posture after each movement in the first minutes after closing his eyes.



Summarizing : In the positions studied a disappearance of antigravity posture was seen at the moment of closing the eyes. This phenomenon was most striking in supine, the position in which the newborns's head and extremities were the least supported.

4.1.5. The newborn asleep in the supine position



State 2

Once asleep the newborn arrived in a more or less comfortable, resting posture, the face turned to the side, the arms and legs were more or less supported in a semi-extended mostly exorotated position.
The facial musculature was not at rest, at all the baby made grimaces and smiled. Rapid and slow eye movements could be observed underneath the closed eyelids. Small twitches in the extremities were present.
The respiration was faster, more irregular in rate and shape than in the quiet awake baby. The respiration depth was quite variable.
The baby was in state 2, or in REM-sleep.
In this epoch the baby remained only briefly in the same posture; occasionally isolated extremity and head movements changed the basic postural configuration. More important changes resulted from frequently occurring gross-body movements in this sleep state.
When the baby closed his eyes with a posture almost identical to the posture while awake, i.e. with the arm still in flexion on the thorax and the legs still somewhat adducted, then after the first series of gross-body movements during sleep a further gliding away was noticed of the arms into an exorated and less flexed posture and of the legs towards a further abducted posture in the hips.
Later during sleep the change in posture resulting after a gross-body movement was hardly predictable at the onset of that movement. Only when a total body movement lasted longer than 30 sec, then sometimes a total flexion of the body occurred with rounding of the back, and then a change-over into a side or partly side position was very probable. During such long postural adjustments some babies vocalised.
In state 2 in the supine position a more extended arm and or leg at the facial side and a more flexed arm and/or leg at the occipital side were observed, this "asymmetric tonic neck posture" was very clearly observable in a few babies.
In other babies the arm was very close to the face and frequently hand-face and hand-mouth contacts were made. Occasionally in state 2 newborns sucked on their hands or on their thumbs in the supine position : more frequently they did it in the full-side and the prone position.
In the supine position in this period with

changing resting postures and total body movements, the location of the baby in his crib frequently changed ; this happened passively, however, without real locomotion.

At about fifteen minutes after the onset of sleep, frequently after a total body movement or a series of such movements, there was a dramatic change. The facial grimacing and twitching stopped, the mouth frequently closed, the facial expression became very peaceful, the eye movements stopped underneath the closed eye lids ; the respiration became more regular in rate and in its pattern of movement, and the baby's posture looked like frozen.
The baby was then in state 1 - in "non REM"-sleep. The posture showed frequently somewhat more flexion in the arms, somewhat more adduction in the legs but this was certainly not the rule for all babies. The main factors influencing this inter- and intra-individual differences were the previous posture in state 2 and the quality and quantity of the movements during the transition.

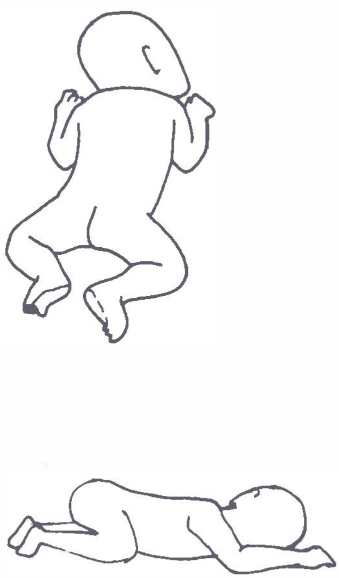
State 1

After a gross body movement at the transition into state 1, an adductor-clonus was observed; namely the legs (which were standing on the bed surface with adducted and flexed hips and with flexed knees), tended to fall aside under the pull of gravity but then an adduction twitch brought them back, subsequently they fell once more, they adducted again and so a clonus occurred.
Once a stable posture was reached in state 1, it remained for the next 15 to 25 minutes.
In state 1 some phasic events, such as sighs and startles occurred. After such a phasic phenomenon, lasting for a maximum of 1-2 seconds, it was amazing to see how the baby reassumed an identical or almost identical posture as before the startle. Such a return could be very slow, and during such a long lasting "relaxation" (10 seconds to several minutes) tonic postures could be observed, e.g. an arm staying a few millimeters above the bed surface for two minutes, a few fingers extended in the air a little bit resembling a catatonia, or a foot slowly returning back into a supported position over a period of 20 seconds.
Some of these relaxations were so slow that we realised only that a movement did occur from the analysis of the time-lapse photos made during the minutes following a startle.
In state 1, never a transition has been noticed from supine into side or partly side, or from side or partly side into supine.

After about 20 minutes with a stable posture, suddenly one realized that the stability was gone : sometimes after a sigh or a startle the respiration did not return to its regular pattern, at other times an arm or a foot glided into a more supported position, or a facial grimace disrupted the posture of the facial musculature. In the next minutes a gross-body movement changed the postural configuration and the eye movements reappeared underneath the closed eyelids. The baby was back in state 2, and for the next 20 to 40 minutes changes in posture were the rule. During the feed-feed interval, lasting 3 to 4 hours, periods with a stable posture and periods with unstable posture neatly alternated ; occasionally this cycle was interrupted by short awake periods with an overall increase of antigravity posture.

4.1.6. The newborn asleep in the orone oosition

In prone, as in supine, periods with changing postures and periods with a stable posture alternated during sleep ; major changes in posture occurred also in prone only in state 2. However, the variation in postures before and after gross body movements and the differences in posture between state 2 and state 1 were small. This can be largely explained by the fact that head and extremities are better supported in prone than in supine, and by the fact that in the prone position a larger friction resists displacements and movements ; since in prone the extremities bear more weight than in supine.
After the onset of sleep, as mentioned above, the first movements resulted in a further turning to the side of the face, and in more abducted and exorotated postures of the extremities. The extremities, instead of lying close to or underneath the body, came into a position around the body (top view). Simultaneously with this change, the buttocks and the contour of the back looked less rounded than in the awake state (side view).
There were babies, however, who did not show these phenomena at all in the first state 2 just after falling asleep ; they had a short state 2 with irregular respiration and with eye movements, but further they remained very quiet and they moved



State 2

quickly into state 1. These babies showed the decrease in overall antigravity posture after the movements in the second state 2, that followed the first state 1.
In state 2, as a result of a series of total body movements, some newborns tilted their pelvis and stretched their legs to the side. By this manoeuvre newborns arrived in a partly-prone, partly side position. These changes in orientation were also in prone strictly limited to state 2. If a baby started a state 1 epoch in such a partly side position he remained in it, and only in a next state 2, or in an awake period he may have returned into a full prone position. Babies turning partly to the side were the babies who showed many extension movements of the legs in all positions and also during feeding.
In state 2 most babies showed head-lifts at the occasion of total body movements. The cheek remained parallel to the bed-surface during short head-lifts. During long head-lifts, the face was brought to the midline and side to side head movements were possible. Especially during the longer head-lifts some babies vocalized.
Locomotion was occasionally the result of a type of crawling but more frequently of push-like movements of the feet and legs. This locomotion was so intense that during a feed-feed interval it was occasionally necessary to reposition the baby in his bed after he reached the edge, a phenomenon also reported by mothers and nurses. Such long lasting motor activities never occurred in a state 1, only a very short head-lift was seen a few times at the transition into state 1. During such gross-body movements the top and the side view of the baby looked as during the awake states, the buttocks were up in the air and the back was more rounded.

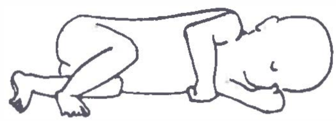
State 1

After one of such gross body movements the newborn's face relaxed, the respiration became regular and deep, and the posture remained the same for the next 15-25 minutes ; the baby was in state 1. In state 1, also in prone, long lasting tonic extension postures of the fingers occurred, the feet stayed frequently with extended toes on the bed surface and the ankle angle showed a small change with each breath.
Startles in prone, in state 1, appeared more like quick and sudden stirs of the baby without actually changing the position of head, body and extremities. In some babies the head-extension slightly increased after a jerk, the face was then a little more up-

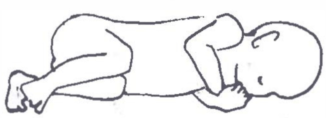
ward compared to the straight or slightly flexed position in state 2. At the transition from state 1 into state 2 mostly no change of posture was observed until a phasic movement took place.

4.1.7. The newborn asleep in the side position

The basic feature, the cycling of a period with a stable posture and a period with frequently changing posture was also present in the side position.
Differences in posture between states were less easy to be observed since the side position is such a comfortable resting position.
The upperlying shoulder and the hip contour were sometimes a little higher in state 1, the upperlying leg was slightly more adducted and flexed in the knee.
In state 2, the gross-body movements always included head movements. But also in the side position it was difficult to predict which posture would be the outcome of these gross-body movements, the baby returned mostly to his initial side position, less frequently into a supine position and rarely into the opposite side position.
After these gross-body movements some newborns glided "passively" into a full supine or into a more pronounced side forward position. Such a passive change in position was never observed in state 1.
Head turning was sometimes the start of a total body movement, sometimes it was imbedded in a movement. Isolated head-turning to the centre and up-wards did occur, and contractions in the upperlying sternocleidomastoid muscle were noticed without associated head movements. One baby of the nine observed in the side position, lifted his head in state 2.
In the side position not all postures looked "comfortable", the upperlying arm sometimes dropped behind the back of the baby. This arm was then exorotated in the shoulder, and semi-extended in the elbow, with the hand either pronated or supinated.
During this posture many and long lasting body movements took place, they made the impression of being efforts to correct this odd arm posture. Sometimes these efforts were not successful and the newborns remained in state 2. Once a baby corrected the situation he immediately changed into state 1.



State 1



State 2

However, in a few babies the change into state 1 occurred without changing the arm position and then it was amazing to see how all movements disappeared and how the strange arms posture was "frozen" for 10 to 20 minutes.
In the side position frequently hand-face and hand-mouth contacts took place during state 2, if those contacts lasted for a while then the baby flexed his head, his back and his arms ; the effect on the legs was not so obvious.

Summarizing remarks on posture and postural behaviour during sleep

It is not meaningful to describe posture and postural behaviour during sleep without taking into account the states and the state cycling.
In state 2 the periods without gross-body movements can be described as absence of antigravity posture or as the postural behaviour the farthest away from awake postural behaviour ; this is most obvious in the supine position.
In the same state 2, however, the total movements are very similar to the active movements in state 4. They result in changes in orientation, in readjustments of posture, in short head-lifts and in locomotion. They differ from gross-body movements in the awake states, in that their onset and especially their end is so abrupt. At the transition from state 2 into state 1 almost each time a gross-body movement or even a series of them is noticed.

In state 1 the posture is somewhat similar to the active postures observed in the awake states. This is most obvious in the first state 1 after falling asleep and in those states 1 which are preceded by gross-body movements resulting in an adequate postural readjustment. In all infants and in all states 1 the observed posture is stable and does not change until the next state 2.
Especially here the question arises : is this stable posture in state 1 only the result of the absence of interfering movements or is it an active controlled posture? The observed cloni in the knees, the long lasting tonic postures in the fingers and toes, and the high regularity of the respiratory pattern are arguments for an active control. In some pilot studies I could not

resist to touch or pull on an arm or a leg and then I felt a resistance and I saw a tendency to return to the initial posture. This problem will be elaborated further in the present study in a series of experiments in which the system is loaded, namely in the rocking experiments. Furthermore after improving the surface EMG an attempt has been made to quantify the muscle activity in the various states and positions.

4.1.8. Return of an active posture when the newborn awakes

In all three positions newborns awoke only out of state 2 never out of state 1. When they awoke either shortly before a feeding, or after a long lasting total body movement, or after the observer woke them up, then awaking behaviour was quite active. The baby awaking in supine stretched and it was amazing to observe how these tonic flexion and extension movements in the newborn look very much alike the awaking movements of older children, and even of adults. Such a stretching period resulted in increased flexion and adduction posture of the arms and in an active either flexion-adduction or an extension abduction posture of the legs. When hungry, the baby started side to side head-turning movements and brought his hands into hand-face and hand-mouth contact.
In prone there was frequently a head-lift during awaking and the extremities were brought back close to, and underneath the body. If hungry, also in this position, side to side head-turning, hand-mouth and hand-sucking behaviour was noticed.
In the side position the newborn sometimes turned his face upwards and ended in a full supine position, or he turned his face towards the bed, mostly after establishing hand-face or hand-mouth contact.
Other times in the middle of a feed-feed interval newborns gently opened their eyes and glanced around; then no major changes were noticed except for the respiration that became more regular in rate and in its movement-pattern.

4.1.9. Position, posture and respiration

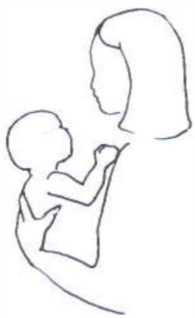
During this study on postural behaviour it was a striking observation that a stable posture went together with a regular respiration.

In prone, in supine and in the side position the quiet awake baby and the baby in state 1 showed a stable posture and had a regular respiration. In state 1 after a startle the head posture became occasionally more extended and subsequently the respiration was very regular.
In contrast, at the onset of sleep, when the active posture fades away, respiration becomes irregular. In state 2, the period with the most unstable posture, the respiration remained irregular. Finally, when the baby awoke the respiration reassumed its regularity.
The regularity of the respiration might therefore be used to differentiate the quiet awake state 3 from the epoch with drowsiness since in this last period, although the eyes are intermittently open, the respiration stays irregular. In chapter 5 the relationship between position-posture and respiration will be discussed further.

4.2. THE NEWBORN CARRIED BY HIS CARE-GIVER

In daily life the human newborn is placed, supported and carried by his care-giver in the prone, supine, side or semi-upright position. The amount of time and the manner in which he is carried vary widely in different cultures. The Hobi developed a cradle board, so their babies are either carried or standing semi-upright during almost the whole day-time (Dennis, 1940).
The Zhun-Twasi or the King Bushmen mothers in Africa, like many mothers of less industrialized societies, carry their babies in a sling. The Zhun-Twa newborn is kept upright and pressed against his mother's side. No clothes separate the infant's skin from the mother's skin (Konner, 1972). Awake and during sleep these newborns adjust their posture by twisting movements of head, arms and legs and by gross-body movements. The adjustments occur spontaneously or they are elicited by changes in the mother's position and posture during her daily life activities and work (Konner, 1972).
The infants in the sling show many hand-movements, grasping of the strands of beads, grasping of mother's skin. They look around and have much eye contact with their mothers and with people around them (Konner, 1972).
During daily life activities of the mothers these infants are constantly moved and frequently rocked.

These mothers make a continuous effort to anticipate hunger or discomfort of their newborns by turning the babies to the ventral side, and by nursing them as soon as they feel, that "his state changes... waking up, moving, gurgling, a change of rate in breathing... any of these may result in nursing" (citation from Konner (1972)).



From these free field observations it appears that postural behaviour has its role in early mother-infant interaction. In a group of Dutch or Belgian mothers the amount and the manner of carrying the newborn will also show strong interindividual differences. Of the three mothers whose babies were studied at home, one had an absolute preference for carrying her baby against her shoulder, the two others used both arm and shoulder carrying. The mother who preferred shoulder carrying had two other young children and (like the nurses in the obstetrical hospital, who also used shoulder carrying) she could occasionally carry the baby with one hand, keeping one hand free for the other children or daily life activities.

From our non-systematical observations a striking fact was the freedom of head and hand movements in the carried babies. Especially when the care-giver gave some support high in the baby's back then the head could turn easily and the baby looked around. The hands grasped clothes or skin and they changed position over the whole arm, shoulder and breast area of the mother. The fact that the arms are so free in the carried position should be compared with the supporting and stabilizing role of the extremities in lying babies (see also Bower, 1974).

State 3

Mothers did not like to take their babies out of the cribs while asleep, spontaneously they gently awoke them, then lifted them up and subsequently carried them while awake.
If I asked the three mothers and two nurses to take and to carry the babies after I evaluated for 5 minutes their behavioural state, the following observations were made : when lifting the babies they mostly awoke ; in state 2 this happened after some postural adjustments. Once awake the newborns stayed awake or returned to sleep while carried against the shoulder. In state 1 they awoke with fussing, showed their discomfort and started crying.
When performing the change from horizontal

State 2

State 1

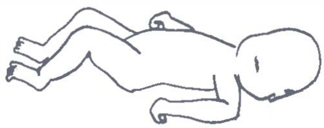
to vertical very slowly the babies continued to sleep, and from these sessions one mother and two experienced nurses without knowing anything about states, commented as follows on the easiness to carry their baby :
In state 1 : "it is very easy-the baby is as a "whole", carrying with one hand on the back is easy possible."
In the awake states : "it is also easy, but the head movements bring the baby "out of balance", when not well supported". Always two-hand support and frequently one hand close to head or neck was used.
In state 2 "it is difficult, the baby is floppy, he glides through the hands", always two-hand carrying was used, like forming a shell around the baby.
These few observations are intriguing and need further elaboration ! A further source of reference for this issue is my carrying of several hundreds of newborns from their crib to the adjacent room for the clinical examination. There is no doubt for me that deviant newborns (both the extremes ; the floppy infant and the hyperexcitable, hypertonic baby) are less adequate partners in early mother-infant interaction ; while the normal baby with some antigravity posture is a stimulus for long and pleasant walks with his parents or care-givers.

4.3. POSTURAL BEHAVIOUR DURING SUCKING

Feeding together with breathing are the most important functions for the immediate and future well-being of the newborn. Their results : weight and weight increase in the first neonatal weeks are the best single predictors of later well-being of a child. The feeding sessions are the moments in which mother-child interaction takes places. It can be expected that the neural programmes controlling this behaviour should be mature at birth. A well developed programme should contain, as an important subroutine, a well adapted postural programme. Thus it is relevant to look in detail to postural behaviour during sucking in newborn infants.

Prechtl and Lenard, 1968, Casaer and Akiyama, 1973, Casaer et al., 1973, described the posture of the active awake hungry newborn at the onset of sucking as follows ; the head is more or less centered, one feels a high neck muscle activity ; the arms are flexed in the elbows and adducted in the shoulders,

the hands fist, the legs are partly flexed and adducted in the hips and extended in the knees.
During the observations made at home, in the nursery and in the observation room before and during the polygraphies this description seemed the general rule, however, there were exceptions.
Therefore in 12 newborns the postural behaviour during *nutritive* sucking in the supine position was studied in more detail. The babies were either horizontal or raised between 0° and 30° from the horizontal. This position was chosen by the care-giver in his attempt to make it confortable for the baby during feeding.
Behaviour was registrated in notes, on photos or by time-lapse cinematography.



The increase in antigravity posture was present in all awake infants (n=10), also in one infant being in state 2, but not in one infant who just went into a state 1 or was very close to the transition into a state 1. This last baby did not show any change at all, although his food intake was adequate at that feeding session.
At the end of the feeding several infants fell asleep, but the disappearance of the posture was more related to the presence or absence of vigorous sucking, than to the behavioural state. At the end of the feeding surely some infants continued non-nutritive sucking when their bottles were empty. If this sucking was still vigorous the sucking posture remained. Qualitative differences at the transition from awake sucking to asleep sucking, or from nutritive to non-nutritive sucking may be present but should be the topic of further studies.
The picture of postural behaviour as described previously seemed to be correct in most cases, although there were some exceptions. The babies showing abduction in the shoulders and the hips during feeding were babies that showed also many abduction movements and postures at other occasions during active awake behaviour, i.e., state 4 and crying, state 5. One baby who showed abduction in the shoulders at the first feeding showed more adduction at the second feeding ; when comparing the two sessions it was noticed that the baby was somewhat more supported in the back during the second feeding and was kept somewhat more upright. The one baby that had his knees flexed during the feedings was also kept in a relatively upright position (30°) and was more like

sitting.
Finally, it was amazing how the feeding postures were intra-individually the same in this small group. Except for one baby, all babies who were in the same behavioural state, during vigorous sucking showed very identical postures during their first and second feedings.

Beside these semi-quantitative results some further interesting observations should be mentioned.
The extension and fanning of the toes seemed to occur at the onset proper, when there was strong extension in the knees.
In one baby also during sucking a strong headpreference to the right (> 10°) was observed. This baby showed the extension of the leg at the face side in a much more pronounced way than at the occiput side ; in the arms and hands no differences were noticed on the photos.

In a few babies the same basic posture of arm flexion and leg extension appeared when nutritive and non-nutritive sucking were attempted in the side position. With this experience non-nutritive sucking in prone was tried and even there the basic pattern appeared. These two last statements need confirmation or rejection.

In the mean time it can be concluded that posture during sucking appears as a total programme, its presence is linked to vigorous sucking. A further study using timelapse or normal speed cinematography with simultaneous time-linked surface polymyographies should be able to elaborate on several of the remaining questions.
Speculating about the question for what this posture could be useful is not difficult ; a stabilization of the head on the body by an increased neck-muscle activity contributes to the efficiency of feeding. For the extremities one should consider the sucking behaviour of human or non-human primates in whom feeding takes place on the mother's body with the infant in the upright position. Then the supporting stretched legs, flexed arms and grasping fingers are obviously essential in stabilizing the newborn during feeding.

Chapter 5

POSTURAL MECHANISMS IN NEWBORN INFANTS

5.1. INTRODUCTION : THE TWO CONCEPTS OF "STATE"

From the qualitative descriptions of postural behaviour in chapter 4, it may be concluded that a newborn has a posture, that his postural behaviour is influenced by his orientation, that his postural behaviour is strongly related to the behavioural states and finally that a vigorously sucking newborn has a specific and mature looking posture. In this chapter an attempt will be made to derive some conclusions with respect to the underlying postural mechanisms.
For the study of brain mechanisms and therefore also for the study of postural mechanisms, the concepts of state are crucial. Therefore in this introduction a short discussion on these concepts is necessary. For detailed discussions on the concepts of the behavioural states, as used in the present study, the reader is referred to Prechtl (1974).
The concept of state in the young infant is used in two connotations : as a descriptive categorisation of behaviour and as an abstract concept of brain mechanisms which modify spontaneous behaviour and responsiveness of the young infant. Prechtl has adopted for his state concept Ashby's definition (1956): "By state of a system is meant any well-defined condition or property that can be recognized if it occurs again"(see Prechtl, 1974).

The first connotation of state is thus a convenient categorisation of behaviour. Criteria to define a state should be cautiously selected. Ashton (1973) warned for the danger of using immediately an interpretative terminology for state descriptions such as "vigilance", "deep sleep - light sleep". "Many researchers include in this way in their terminology what only their experiments could have told them, the danger of circular reasoning is imminent", citation of Prechtl (1974). The state criteria used in the present study, (Prechtl and Beintema, 1964), are purely observed criteria. The polygraphic recording is only a technical aid to continuously monitor states and state-cycles.

The second connotation of state is phrased as follows : "States are distinct conditions, each having its specific properties and reflecting a particular mode of nervous system functioning " citation of Prechtl, (1974). In this context state is not a convenient behavioural category used to study something else; but states are studied in their own right. This approach proved to be useful in elaborating on underlying brain mechanisms in a whole series of studies. The design of these studies can be broadly described as follows : state is continuously monitored by a polygraphic recording, stimuli of various sensory modalities are regularly applied, variations in the intensities of the responses under study are measured from the recordings in relation to state. In system theory such an approach is called an analysis of input-output state relations.

TABLE 5.1.

Responses to stimulation in different states
(adapted from Prechtl 1974)

	State I	State 2	State 3
Proprioceptive reflexes			
Knee jerk	+++	±	++
Biceps jerk	+++	±	++
Lip jerk	+++	±	++
Ankle clonus	+++	−	−
Moro tap	+++	−	++
Moro head drop	+++	−	++
Exteroceptive skin reflexes			
Tactile			
Rooting	−	−	++
Palmar grasp	−	+	++
Plantar grasp	−	++	++
Lip protrusion	−	+++	++
Finger reflex	−	+	++
Toe reflex	−	++	++
Tibial reflex	±	++	++
Fibular reflex	±	++	++
Axillary reflex	±	++	++
Pressure			
Babkin	−	+	++
Palmomental	−	++	++
Nociceptive			
Babinski reflex	++	+++	+++
Abdominal reflex	++	+++	+++
Thigh	++	+++	+++
Pubic	++	+++	+++
Inguinal	+++	+++	+++
Auditory orienting	±	++	+++
Visual pursuit	−	−	++
Vestibulo-ocular	−	++	+++

In table 5.1. adapted from Prechtl (1974), the main results of these studies are summarized. From those studies conclusions can be derived as to the mechanisms underlying the organisation of the behavioural states.
But it is as legitimate to draw conclusions as to the mechanisms that handle imputs of various sensory modalities, e.g. the exteroceptive stimuli lead only to motor responses in the awake newborn and in the newborn asleep in state 2, while in state 1 no or minimal responses are observed; nociceptive stimuli however result in motor responses in all states. These results do not only tell something about state, but they show that there are differences between the mechanisms that handle exteroceptive inputs in the neonate and those mechanisms which handle the nociceptive inputs.

In a first series of experiments, in the present study state was used only as a convenient behavioural category. In these experiments the newborns were placed in the prone, in the supine and in a sitting position, and the effect of these positions on the behavioural states and on several behavioural and physiological concomitants of the behavioural states was studied. Since states themselves are quantitatively not strictly homogeneous (Prechtl, 1974), behavioural and physiological phenomena within the states were studied. Part of those inconsistencies resulted from the motility during the states, e.g. the startles in state 1, the gross-body movements in state 2. A detailed study of the relationship between position, posture and motility within the states was thus considered to be interesting.

In a second series of experiments the postural system was loaded in the various behavioural states; newborns have been continuously rocked, either about their midthoracic transverse axis or about their longitudinal axis. Differences in postures and postural reactions were studied in the various behavioural states. Special attention was given to the relative position of head and body during continuous longitudinal rocking.
It is obvious that head posture is an essential part in the total body posture. On one hand the head contains the eyes , the ears and the vestibula, on the other hand the muscle spindles, the tendon-and joint-receptors of the neck form a very refined propioceptive sub-system in the postural control system.
Finally, changes in postural behaviour have been directly related to measured changes in muscle activities. Also here special attention was paid to the activities of the neck muscles.

5.2. COMPARISON OF POSTURAL BEHAVIOUR OF NEWBORNS IN A SUPINE HORIZONTAL AND IN A SUPINE SEMI-UPRIGHT POSITION

The broad outline of the first series of experiments has been derived from daily life observations, and from the idea that in some cultures newborns are carried much more than in others and that they consequently spend much more time in a semi-upright to upright position.

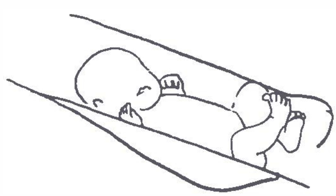
If some degree of postural control exists in the newborn, then it should be possible to demonstrate significant differences in the behavioural repertoire of newborns placed in two clearly different orientations in the field of gravity : namely lying supine horizontal" (0°-position") or sitting supported in a baby-seat (with the longitudinal body axis approximately at an angle of 60° from the horizontal (60°-position).

5.2.1. Qualitative description

In a first paragraph qualitative aspects of behaviour in the baby-seat will be described. These data are derived from the observation of 11 newborns (groups D in table 2.1.). Five newborns formed a pilot group. Of one newborn photos were made in the baby-seat during the various behavioural states; and three newborns were recorded on video-tape for a total amount of 6 hours. These observations, and especially the possibility to analyse and reanalyse the video-tapes, made it possible for the observers to become more acquainted with behavioural categories in this unusual position.

Awake behaviour in the baby-seat

The awake infant in the baby-seat remained in state 3 for long epochs. His eyes were bright and at several occasions he made scanning eye movements. A few babies looked as if they fixated their own image in the nearby mirror. This visual alertness of young infants in a more upright position was already mentioned by Gesell, (1945), and has been well documented in a group of 64 newborns by Korner and Thoman (1970). In studies on cognitive functioning in early infancy, the sitting position is therefore considered to be the ideal experimental situation (Bower, 1974).



Awake

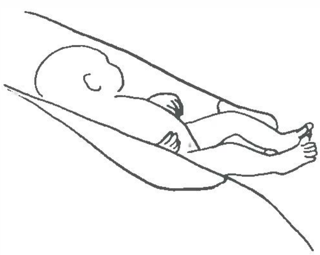
The active awake newborn (state 4) in the baby-seat moved his head more free and a head preference was not as obvious in the baby-seat as when lying supine, in sitting newborns the face was more frequently observed to be in the midline. In the baby-seat some postures made a much stronger impression of being antigravity postures e.g. a leg freely extended from the knee or hip onwards, or a fore-arm extended in the air above the baby-seat. Gross-body movements in the baby-seat appeared frequently as a sequence or as a chain of movements. An example : a leg was abruptly extended, by this the head and trunk were pulled forwards but immediately a backward head and body movement counteracted this movement and this brought mostly the baby back into a resting position. Other gross-body movements did not start with a movement of an extremity but right away the head and total body seemed involved, they resulted in a repositioning of the baby in a more extended and comfortable posture.

The transition from wakefulness to sleep in the baby-seat.

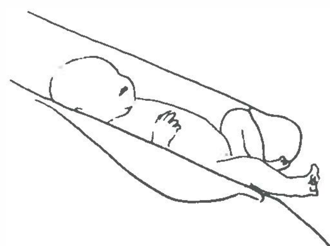
When the eyes closed, the head sank on the thorax or on a shoulder, arms and legs dropped into a passive contact with the baby-seat or with the body. Sometimes this went gradually, at other times this happened abruptly. In the last case frequently a gross-body movement or a startle followed, then the baby opened his eyes again, awoke and incidentally even fussed.

The newborn sleeping in the baby-seat

Once asleep the newborn slumped, the respiration became more irregular and faster. This fast respiration was interrupted by sighs or at the occasion of gross-body movements, by bursts of deep and slow breaths, the baby was in state 2. Gross-body movements were, as in the awake state, either a type of "chain of movements", or they were immediately total body movements, which resulted in a repositioning of torso and head in a more extended and frequently a more symmetrical posture. Total movements in the baby-seat appeared to last longer than in the crib.
After such a gross-body movement the baby could suddenly remain in a certain posture; the respiration became deeper and slower; the posture did not change anymore for the next 15- to 25 minutes, the baby was in state 1.
In the baby-seat the temporal relation between a stable comfortable posture and a regular respiratory pattern was obvious.



State 2



State 1

In the baby-seat the amplitude of a startle could be very large. After the startle occasionally a total body movement, a repositioning, occurred, this was rarely seen in lying newborns in state 1. At the occasion of a large-amplitude startle (with or without a subsequent gross-body movement) state 1 could abruptly change into state 2, or even in the awake state, then mostly the newborn fussed or cried. In the whole group of infants in the horizontal position *awaking out of state 1* has never been observed. Theorell et al. (1973) reported that newborns in the supine position in their first postnatal hours but not on their 5th day occasionally awoke out of state 1. Many changes take place in the first day of life , one is the dramatic increase in gravitational stress, and this is the factor also present in the baby-seat!
Beside this unusual abrupt end of state 1, the usual transition into a

state 2 was characterized by a "fading away of posture", as seen at the onset of sleep; namely the head and thorax slumped and the respiration became more shallow.
In the baby-seat, like in supine, the rule was to awake in a state 2. The newborn opened his eyes frequently during a gross-body movement; afterwards either he remained quiet and looked around or he became very active; then he started with side to side movements of the head and he fussed. If the care-giver did not react with providing a next feeding the newborn became upset.

Summarizing the qualitative description

Newborns look comfortable both in the baby-seat and in the crib. A qualitatively different behaviour is the observation that newborns in the baby-seat awake out of state 1. The presence of tonic movements in state 1 regularly observed in the baby-seat is also rather unusual in lying newborns.
The other behavioural categories are present in both positions, in the baby-seat, however, they are much more striking as active antigravity activities than in the lying position. The gross-body movements in the sitting newborn both awake and during sleep look like real resets in body posture; the fading away of antigravity posture at the onset of sleep is easier to see in the 60°-position, and finally the link between regular respiration and a stable posture in state 1 and in state 3 is more obvious in the semi-upright position.

5.2.2. Quantitative results

5.2.2.1. *Subjects and methods*

Six newborns (group D' of table 2.1) aged 5-7 days, with birth weights between the 25th and the 90th percentile were the subjects for this behavioural and polygraphic study.

From the literature, from previous studies in our institute and from the pilot study it was plausible that beside the imposed orientation the following facts also have an influence on neonatal behaviour and therefore they should be controlled as much as possible in the experiment :
1. the position before the first experimental position,
2. the fact of changing the position,
3. the sequence of the experimental positions,
4. the influence of the feedings,
5. the time of the day,
6. the fact of being brought into a laboratory setting.

Furthermore during the pilot study the individual differences of the babies in their reactions to positional changes were impressive. Therefore each baby was made his own control and the experiment went as follows :
1. all six newborns were nursed in a side position before the experiment,
2. the number of positional changes was limited to two,
3. after the 1st feeding three babies started in the 0°-position, the three other babies in the 60°-position,
4. halfway in each recording, three babies were changed from 0° to 60° and the other three from 60° to 0°,
5. the time of the positional changes coincided with the feeding sessions,
6. all recordings took place between 9 a.m. and 4 p.m.

Since all comparisons are within the same individual the sign test has been used.

5.2.2.2. *The behavioural states and the behavioural state cycle in the supine horizontal and in the supine semi-upright position*

Are newborns really more awake when postural load is increased , and is the decrease in the amount of sleep equally distributed over the two sleep phases ? This question should be considered in the light of the following facts : state 2 is the sleep-phase in which the active posture seems to disappear but also the sleep-phase during which readjustments happen, and state 1 is the sleep-phase in which posture looks very stable, also in the baby-seat.
Based on the visual analysis of the polygram, i.e. the on-line write-out of the physiological signals during the whole experiment, the moment of on-set and end of the various behavioural states is determined. The change in the respiratory pattern is used as the cutting point for the state 1 into 2 and state 2 into 1 transitions. At least 3 minutes of a new state should follow after such a change, to accept an epoch as a state and not merely as an interfering irregularity in an ongoing state.
From such an analysis the state profiles of the experiments were derived, see fig. 5.2.-1.

Also the following parameters were obtained :
1. duration of the individual behavioural states
2. percentages of time spent in each state
3. the longest state cycle : this means the longest combination of a state 1 and 2, or state 2 and 1 available during the observation
4. the number of state transitions in the observation.

TABLE 5.2-1

Percentage of time spent in each state
(Lying supine horizontal - 0°-versus supine semi-upright - 60°-)

Baby	State 1			State 2			Awake (St.3-4-5)		
	0°		60°	0°		60°	0°		60°
1900	42	<	44	58	>	46	0	<	10
1905	28	>	27	72	>	60	0	<	13
2519	35	<	40	59	>	50	6	<	10
1923	31	<	40	68	>	58	1	<	2
1953	28	<	41	72	>	35	0	<	24
2012	40	>	38	57	>	47	3	<	15
sign. test		n.s.			$p < 0.05$			$p < 0.05$	

In tables 5.2-1 and 5.2-2, the percentage of time spent in each state in the two positions and the mean duration of each state in the two positions are listed.
In tables 5.2 -3 and 5.2 -4 the longest cycle per infant and per position and the number of state transitions per infant and per position can be seen.
From figure 5.2 -1 and these tables it can be concluded that the orientation in the field of gravity has effects on the neonatal behavioural state cycle.
Newborns in the baby-seat were more awake and they stayed longer awake, they showed a smaller amount of state 2, and their states 2 were shorter.
Their percentage and duration of state 1 were not affected.

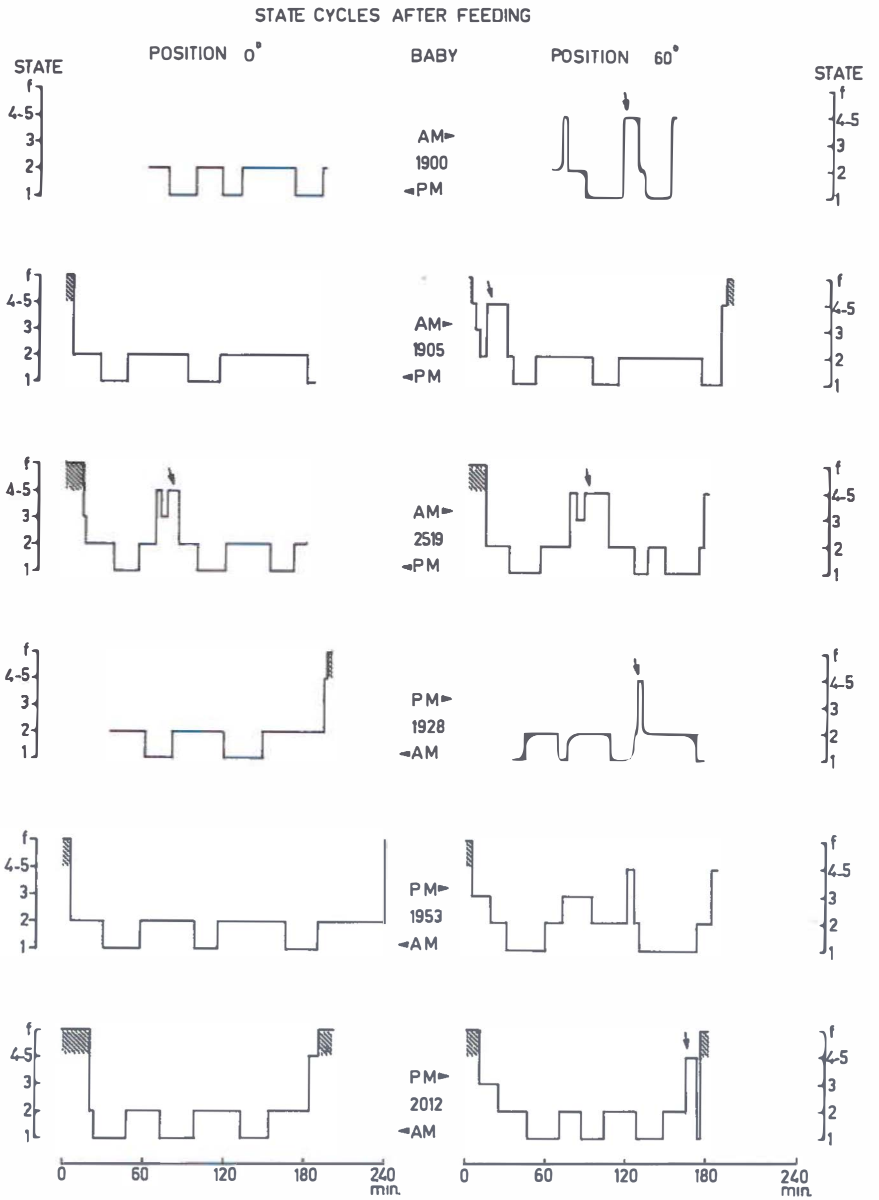


Figure 5.2.-1. Behavioural state profiles of six newborns, aged 5-7 days, in two different positions, lying supine horizontal (position-0°) and supported supine semi-upright in a soft baby seat (position-60°).

- *The vertical scales indicate the behavioural states; "f" means feeding, the feeding period is crosshatched.*
- *The horizontal scale is time in minutes. In each position the origin of this scale is the onset of feeding. If for nursing or technical reasons*

TABLE 5.2-2

Mean duration of each state in minutes
(Lying supine horizontal - 0° - versus supine semi-upright -60°-)

Baby	State 1			State 2			Awake (St.3-4-5)		
	0°		60°	0°		60°	0°		60°
1900	19	<	24	25	>	18	0	<	3
1905	22	>	21	55	>	28	0	<	8
2519	19	<	20	21	>	15	10*	<	14*
1928	25	>	18	42	>	25	2*	<	4*
1053	22	<	37	39	>	13	0	<	14
2012	24	>	21	33	>	19	5*	<	15
sign. test	n.s.			$p < 0.05$			$p < 0.05$		

* only one value

TABLE 5.2-3

The longest cycle in minutes
(lying supine horizontal - 0° - versus supine semi-upright -60°-)

BABY	0°		60°
1900	60	>	48
1905	89	>	82
2519	55	>	45
1928	75	>	50
1953	75	>	55
2012	69	>	45
sign test	$p < 0.05$		

TABLE 5.2-4

The number of transitions per hour
(lying supine horizontal - 0°-versus supine semi-upright -60°-)

Baby	0°		60°
1900	3	<	4
1905	2	<	3
2519	3	<	4
1928	2	<	3
1953	2	<	4
2012	3	<	4
sign test	$p < 0.05$		

a part of the recording following a feeding could not be used, the corresponding segment of the recording was also deleted after the other feeding (see babies nr. 1900 and 1928).

- *AM and PM indicate in which part of the day the baby remained in a particular position.*
- *Arrows on the profiles indicate when pacification was required for periods of crying lasting at least 3 minutes.*

The duration of the longest cycle (state 1-2 or state 2-1) was shorther in the baby-seat.
The number of transitions per unit of time was higher in the sitting than in the lying position.
The last two points reflect the fact that the behavioural state cycle in the baby-seat was more disrupted; this was due to the increased incidence of awaking in the sitting babies.

5.2.2.3. *Gross-motor activities in the supine horizontal and supine semi-upright position*

From the pilot study a part of the gross-body movements in state 2 appeared as postural readjustments, others appeared as reactions to, or after-effects of randomly occurring extremity movements.
Therefore, the questions to be answered are :
Are there more gross-body movements in the sitting than in the lying babies?
Are the durations of the gross-body movements longer in the baby-seat than in the crib?
Are the intervals between gross-body movements shorter?

To answer these questions the polygrams were visually analysed. During all recordings beside the chin EMG, at least 4 other surface EMGs were recorded; namely M. Biceps and M. Quadriceps at both sides. The quality of these EMG recordings did not allow us to evaluate consistently long-lasting small tonic muscle activities this in contrast to the new EMG recordings developed later-on during this project. From this limitation it was decided not to differentiate between tonic and phasic activities but to accept as a gross-motor activity the seconds in which at least 3 out of 4 muscles were active.

From figure 5.2-2 and table 5.2-5 it is clear that the newborns in the baby-seat showed an increase in gross-motor activity in state 2.

From table 5.2-6 it appears that part of the explanation is that movements are longer in the baby-seat. In tables 5.2-7 the number of gross-motor activities per 10 minutes in the six babies are displayed. These results do not show significant differences.
Further analyses as to which muscles in what combinations were active have not been performed since the interindividual differences in posture and in postural adjustments in the baby-seat were under this environmental conditions too variable.

TABLE 5.2-5

Percentage of time in state 2 with gross-motor activity (lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	0°		60°
1900	9.5	<	14
1905	5	<	12
2519	10	<	16
1928	15	<	18
1953	7	<	15
2012	12	<	15
sign test		$p < 0.05$	

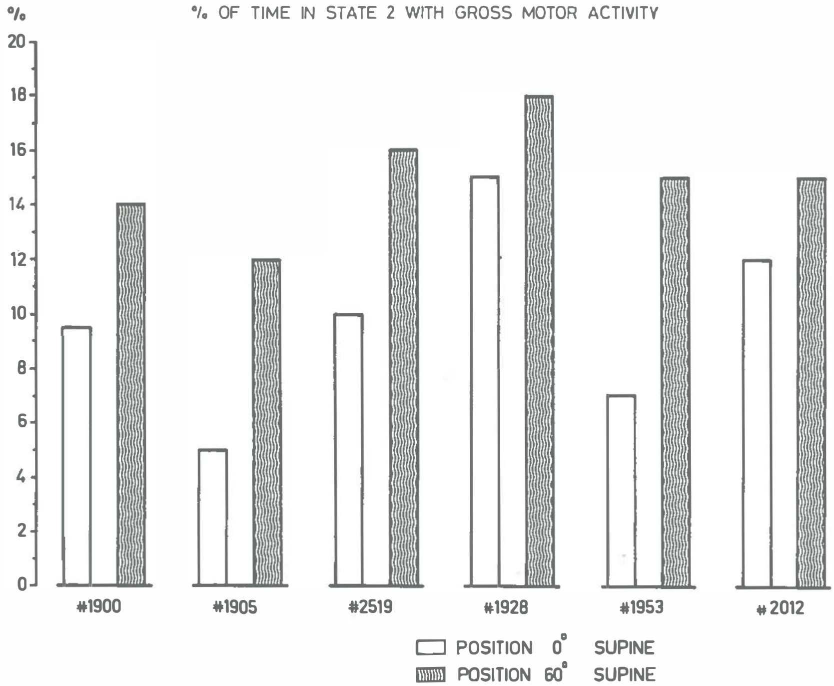


Figure 5.2.-2. Percentage of time in state 2 with gross-motor activity. In each baby the percentages of time in state 2, in which three out of four EMG recordings showed muscle activity, are compared in the supine horizontal (position-0°-) and in the supine semi-upright (position -60°-) positions.

TABLE 5.2-6

Mean duration in seconds of gross-motor activities in state 2 (lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	0°		60°
1900	10	<	29
1905	8	<	16
2519	22	<	23
1928	7	<	36
1953	17	<	30
2012	4	<	9
sign test		p < 0.05	

TABLE 5.2-7

Mean number of gross-motor activities per 10 minutes in state 2 (lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	0°		60°
1900	5.26	>	4
1905	3.6	<	4.8
2519	3.8	<	4
1928	2.2	<	4.5
1953	3.7	<	4.7
2012	5.5	<	6
sign test		n.s.	

The sitting baby was thus not only more awake and more active while awake, but in state 2 (the state in which gross-body movements usually occur in sleep), the gross-motor activities increased when postural load increased. In state 1, the only gross-motor activity is the startle, a sudden movement of head, body and extremities lasting only a few seconds. In the analyses of the number of startles per total state 1 time, per state and per unit of time no differences were found between the lying or sitting newborns. This does not mean, however, that position has no effect; from our observational notes and from the video-tapes it appeared, that the head to body relation was intraindividually very variable in these babies and this is surely a factor to be controlled in any experiment that intends to look specifically at startles !
An exciting finding was that four out of six babies in the baby-seat showed at one or more occasions in state 1 gross-body movements. This was observed in only one out of these four babies in the lying position. Theorell et al. (1973) reported that gross-body movements in state 1 do occur on the first day of life but not on the fifth. Again a parallel appears between the first day of life and the -60°- position; is the common underlying factor the increase in postural load ?

5.2.2.4. *Respiration in the supine horizontal and in the supine semi-upright position*

From the pilot study a striking temporal relationship between posture and respiration appeared, namely the association between a stable posture and regular respiration, and the association between the disappearance of an antigravity posture at sleep onset and the change in respiratory rate and regularity.
Therefore in this section a closer discussion of the differences in respiratory parameters in the 60°- and the 0°-position will be presented. After analogue-to-digital conversion of the respiratory signal, the 50th percentile and the interquartile range of the distribution of the breath-breath intervals were computed per 3 minutes. These results were plotted in sequential diagrams, see fig. 5.2-3 for a sequential diagram of 50th percentiles of breath-breath intervals and of heart-beat intervals, and see fig. 5.2-4 for a sequential diagram of the interquartile ranges of breath-breath and heart-beat intervals.
These values are expressed in milliseconds; the 50th percentiles can be converted into corresponding frequencies per minute. These last values are, however, not equal to counted breaths per minutes since all intervals

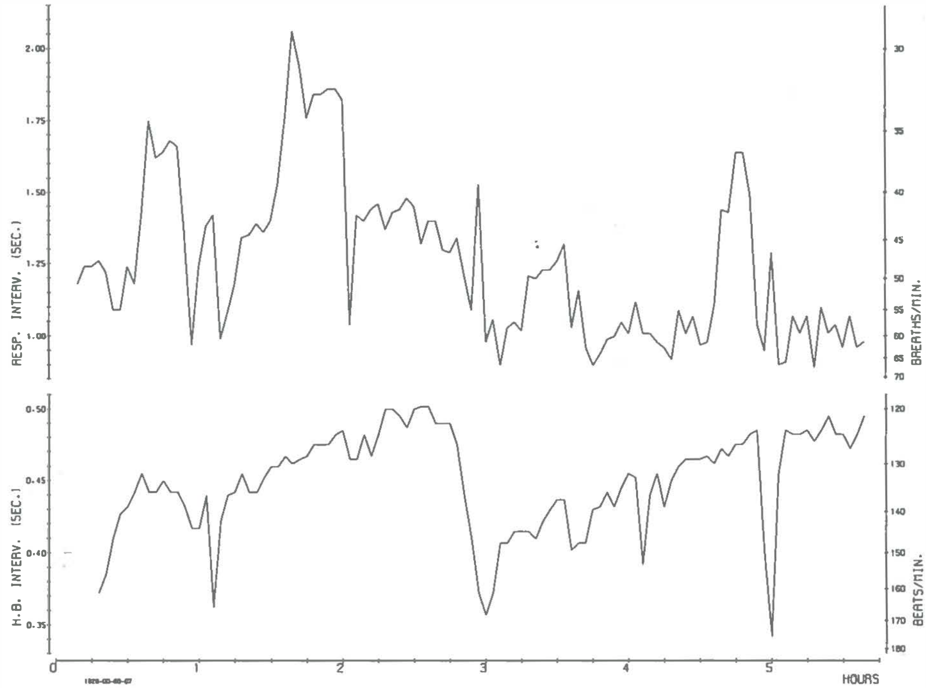


Figure 5.2.-3. Sequential histogram of the 3 minute median breath and heart-beat interval values (converted values into rate/min on the right side of the graph). The newborn (age 7 days) is in the -0°-position up to 3 hours, afterwards he is in the -60°-position

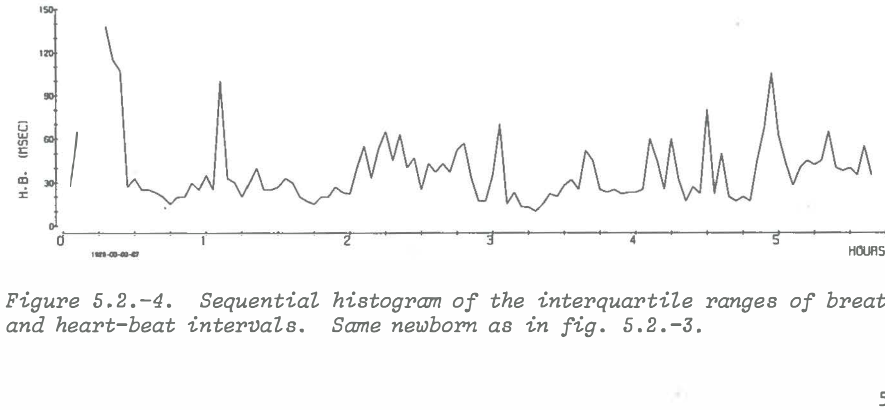


Figure 5.2.-4. Sequential histogram of the interquartile ranges of breath and heart-beat intervals. Same newborn as in fig. 5.2.-3.

longer than 4 seconds were excluded from the calculations (for a discussion on this method see Scholten, 1976). In general, however, this method allows us to describe overall trends with a slight underestimation of the slower rates and a slight varying distortion of the interquartile ranges.

Respiratory rate

The means of the 50th percentiles of the breath-breath interval distributions of all 3'epochs are listed in table 5.2-8. The corresponding frequencies are listed in table 5.2-9. All six babies, regardless of the fact if they were first in 0° and later in 60° or vice versa, breathed faster in the 60°-position. This is a significant result at the 0.05 level (sign test).

TABLE 5.2-8

Mean in milliseconds of the 50th percentiles of breath-breath interval-distribution of all 3' epochs (lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	State 1			State 2			Total observation		
	0°		60°	0°		60°	0°		60°
1900	1510	>	1182	1423	>	810	1193	>	850
1905	1547	>	1156	1406	>	1116	1395	>	1176
2519	1340	>	1146	1078	>	1070	1137	>	1073
1928	1873	>	1538	1377	>	999	1464	>	1101
1953	1958	>	1759	1704	>	1536	1782	>	1558
2012	1427	>	1014	1578	>	1132	1452	>	1089
sign test	p	<	0.05	p	<	0.05	p	<	0.05

TABLE 5.2-9

Corresponding respiratory frequencies per minute (lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	State 1			State 2			Total duration		
	0°		60°	0°		60°	0°		60°
1900	40	<	51	42	<	74	50	<	71
1905	39	<	52	43	<	54	43	<	51
2519	45	<	52	56	≤	56	53	<	56
1928	32	<	39	44	<	60	41	<	54
1953	31	<	34	35	<	39	34	<	38
2012	42	<	59	38	<	53	41	<	55
sign test	p	<	0.05	P	<	0.05	p	<	0.05

After splitting up these values in state 1 values and state 2 values, a similar trend was found in each baby; each baby breathed faster in the 60° position both in state 1 and in state 2 (see tables 5.2-8 and 5.2-9).

Respiratory regularity

If one calculates the mean of all consecutive interquartile ranges or of all values in state 1 or in state 2, not such clear changes are seen between sitting and lying newborns.
If the ratios in between the means of the interquartile ranges and the means of the 50th percentiles are calculated an overall measure for the irregularity of the respiration per state and per orientation can be derived, e.g. an interquartile range of 240 milliseconds and a 50th percentile of 1200 milliseconds give a ratio of 0.20.
In table 5.2-10 the ratios per state and pėr position of each newborn are listed.

TABLE 5.2-10

Ratios of the averaged interquartile ranges to the averaged fiftieth percentiles of breath-breath intervals of all 3 min. epochs in state 1 and in state 2 (lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	State 1			State 2		
	0°		60°	0°		60°
1900	.17	=	.17	.42	<	.52
1905	.14	<	.22	.43	<	.48
2519	.15	<	.20	.29	<	.38
1928	.12	<	.17	.21	<	.35
1953	.16	=	.16	.40	<	.50
2012	.15	<	.20	.38	<	.50
sign test		n.s.			p < 0.05	

In the baby-seat all six newborns showed an increase in the respiratory irregularity in state 2, this is a significant result at the 0.05 level (sign test).
In state 1, however, the state in which a certain degree of postural control is presumed, no significant increase in the respiratory irregularity was observed. The newborn, thus showed a better adaptation to this postural load in state 1 than in state 2.

Is the sigh related to a reset in respiration and postural control?

In the breathing pattern of the newborn a very typical interruption may appear : a sigh (see figure 5.2-5). The sigh consists of a deep inspiration followed by a deep expiration, afterwards respiratory rate and movement-pattern stay somewhat irregular for about 5 to 20 seconds to resume subsequently the basic respiratory pattern. The sigh is easiest to study in state 1, since the basic respiratory shape and pattern is very regular. The sigh exists also in state 2 but there it is not so easy to identify in the ongoing irregularities of respiration; in state 2, it is easier to identify a sigh behaviourally than on the basis of the thermistor write-out. In state 1 frequently a startle happens at the occasion of a sigh, most frequently during the deep inspiration (Akiyama, 1968). At that moment a small head extension movement is frequently observed or at least it can be concluded to have occurred by comparing posture before and after the sigh.

There are several speculations possible about the mechanisms controlling this phenomenon.
One attractive hypothesis is that the sigh is triggered off by the information from alveolar collapse receptors. In normal breathing continuously different parts of the lung are ventilated or partly collapsed. A continuously changing flow of impulses from the collapse receptors modulates the respiratory centres. The presence of neural structures in the lung parenchym is a well-established fact in the human neonate (see Lauwerijns and Cokelaere 1973), about the function of these structures one can at present only speculate.

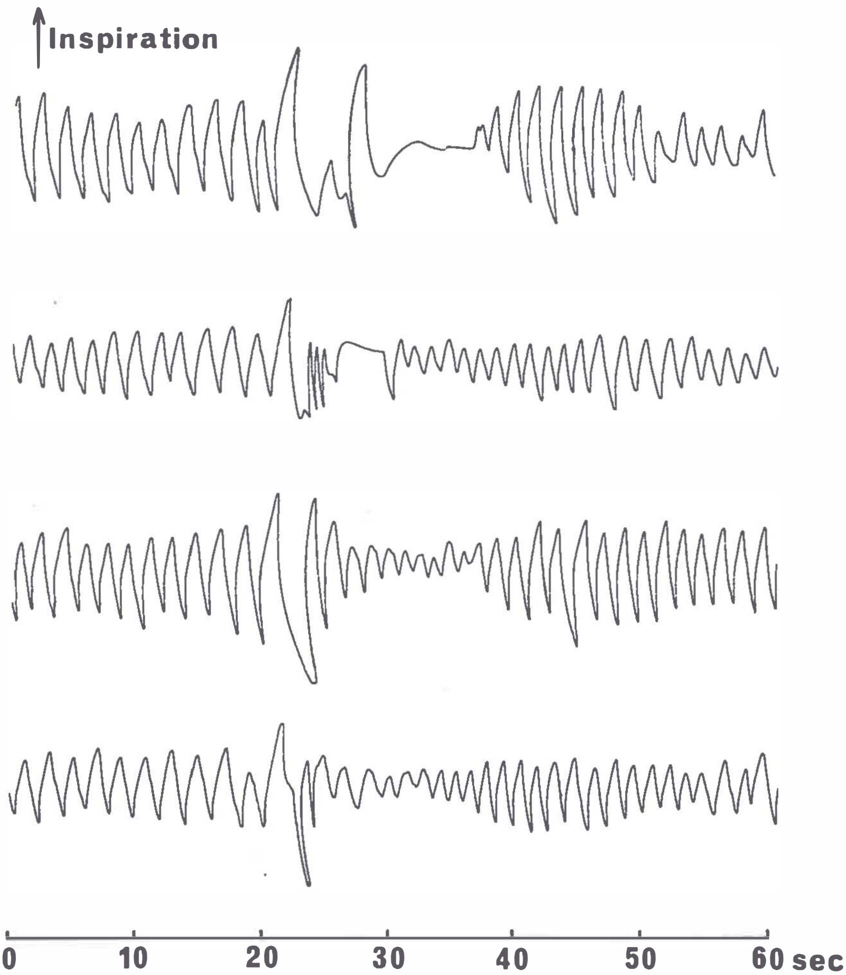


Figure 5.2.-5. Four tracings of respiration at the occurrence of a sigh in state 1. Inspiration of air is depicted in the upwards directions in the tracings.

If too large a part of the lung is too much or too long collapsed, the inflow of the receptors would reach a critical level and a sigh is released, resulting in a very alveolar readjustment.
Another possible mechanism would be that a sigh is triggered by signals having as origin pressure or proprioceptive receptors in or around the airways. The sigh would then optimize the shape of the upper airway tract, see the small head extension observed at several occasions at or after a sigh.
A third related speculation is that the sigh results from information out of the proprioceptors of the intercostal muscles and joints. The sigh would result in a boost in the intercostal muscle activity. Those muscles seem to play a role in both postural control and breathing (see paragraph 6.2.2). All three hypotheses have one speculation in common : the sigh would be an adaptation, a reset mechanism.

Since all the newborns were breathing faster in the sitting position, and since the sitting position surely was a load for a system controlling respiratory volume, it was interesting to compare the sighs in both the sitting and the lying positions.
The moments at which sighs occurred were determined on the polygrams. Since a sigh frequently occurred at the transition from state 1 into state 2, that sigh at the transition was excluded from the further calculations. From those moments, the intervals between two sighs were determined. The number of sighs per state was converted into the rate of sighs per 10 minutes; the average of these values of a given state in the 60° position was then compared with the averaged value of the sigh rates of a given state in the 0° position.

TABLE 5.2-11

Mean interval in seconds between two sighs in state 1
(lying supine horizontal - 0° - versus supine semi-upright-60°)

Baby	0°		60°
1900	450	>	325
1905	720	>	290
2519	180	>	125
1928	600	>	380
1953	480	>	140
2012	420	>	285
sign test		$p < 0.05$	

TABLE 5.2-12

Mean number of sighs per 10 minutes of state 1
(lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	0°		60°
1900	0.6	<	1.6
1905	0.8	<	2.0
2519	3.0	<	4.8
1928	1.0	<	2.0
1953	0.6	<	4.3
2012	1.5	<	2.0
sign test		$p < 0.05$	

All six newborns showed shorter intervals between sighs and had a higher rate of sighs in the baby-seat as compared to lying in the crib (see tables 5.2-11 and 5.2-12).
From these results our question (Is the sigh related to a reset in respiration and posture?) gets a positive answer.

5.2.2.5. *Heart rate in the supine-horizontal position and in the supine semi-upright position*

Changing the position may lead to changes in the circulation and its neural control, that can be evaluated by studying blood pressure, heart rate and heart rate variability. Although until now such changes have almost not been studied in the newborn, it seems that just after a change in position there are short-lasting adaptations resulting in new stable settings (see CROSS, 1974, DAWES, 1968, SHINEBOURNE, 1974).

In the baby-seat the heart rate was slightly faster in all six babies ($p < 0.05$), the differences were, however, minimal in several infants if expressed as the mean of all 50th percentile values or as the corresponding heart-beat frequencies (see table 5.2-13, 5.2-14). The values in state 2 and state 1 separately did not show significant differences. It is very plausible that part of the differences could be explained by the amount of movements while awake or while asleep and by the effort of the respiratory muscles.
From figure 5.2-3 it can be seen (in baby 1928) that a decline in heart-rate from one feeding to the other started from a somewhat higher level in the 60°- at 3 hours than in the 0°-position and further that a peak in the heart rate appeared at the occasion of a short awake state, at about 5 hours; those values suffice to explain the slight differences in the median heart rate of 454 to 445 milliseconds (see table 5.2-14).

TABLE 5.2-13

Mean in milliseconds of the 50th percentiles of heart-beat intervals distributions of all 3'epochs (lying supine horizontal -0°- versus supine semi-upright -60°-)

Baby	State 1			State 2			Total observation		
	0°		60°	0°		60°	0°		60°
1900	458	>	435	440	>	420	430	>	414
1905	621	>	541	532	>	514	564	>	511
2519	548	>	502	492	<	532	511	>	506
1928	473	>	472	451	<	480	454	>	445
1953	536	<	542	535	>	499	529	>	486
2012	630	>	519	557	>	509	554	>	502
sign test	n.s.			n.s.			p	<	0.05

TABLE 5.2-14

Corresponding heart-beat frequencies
(lying supine horizontal 0° - versus supine semi-upright -60°)

Baby	State 1			State 2			Total observation		
	0°		60°	0°		60°	0°		60°
1900	131	<	138	136	<	142	139	<	149
1905	97	<	110	113	<	117	106	<	117
2519	109	<	119	122	>	113	117	<	118
1928	127	=	127	133	>	125	132	<	143
1953	112	>	110	112	<	120	113	<	123
2012	95	<	116	108	<	118	108	<	119
sign test	n.s.			n.s.			p < 0.05		

Heart rate irregularity

As an index for heart rate irregularity here also the ratios between the interquartile ranges and the fiftieth percentiles of the beat-beat intervals were calculated : they are listed in table 5.2-15. No systematic differences in irregularity are seen, neither in state 2 nor in state 1, when comparing the 60°-position with the 0°-position.

TABLE 5.2-15

Ratios of the averaged interquartile ranges
to the averages 50th percentiles of heart-beat intervals
of all 3' epochs in state 1 and in state 2
(lying supine horizontal - 0° - versus supine semi-upright - 60°-)

Baby	State 1			State 2		
	0°		60°	0°		60°
1900	.02	<	.03	.08	>	.06
1905	.09	<	.11	.12	=	.12
2519	.07	>	.06	.09	>	.06
1928	.04	=	.04	.06	<	.09
1953	.04	<	.05	.07	=	.07
2012	.13	=	.13	.13	>	.10
sign test	n.s.			n.s.		

Better than trying to retrospectively analyse, interprete and reanalyse these values it should be said that for meaningful evaluation of causal relations between position and heart rate, a time window much smaller than the 3 minutes epoch should be used in the analysis, and furthermore a type of correlation analysis in which continuously respiratory rate (taking into account the apnoes) and a parameter for motor activity should be included. This methodology is elaborated in the study of Scholten (1976).

5.2.2.6. *The eye movements in the supine horizontal and supine semi-upright position*

The newborn has two main classes of eye movements : slow rolling eye movements (SEMs) and rapid eye movements (REMs). The eye movements can be observed visually when the baby's eyes are either open or closed, and they can be recorded with the aid of electro-oculography (see paragraph 3.5). A hard-ware circuit, developed in the department, enabling an on-line detection of REMs, was not yet available during this part of the present study.

In 1955 Aserinsky and Kleitman described the sleep phase with REMs. From that moment onwards several researchers used REMs as one of the physiological parameters in neonatal sleep research (see Monod and Pajot, 1965, Parmelee et al., 1967 and Anders et al., 1971).
Prechtl and Lenard (1967) studied in detail eye movements in sleeping newborn infants, who were lying in the supine horizontal position. The main conclusions of their study can be summarized as follows :
There are no eye movements during state 1.
In state 2, from the beginning to the end, slow rolling eye movements are continuously present; on top of those SEMs the REMs are superimposed; the REMs do not occur until 2 to 4 minutes after the onset of the first slow eye movements, and the REMs disappear a few minutes before the SEMs disappear at the end of state 2.
Related in time to phasic increases in the amount of REMs the following changes in physiological variables were demonstrated : an increase in the frequency and in the irregularity of respiration, an increase in the amount of small muscular twitches and a depression of monosynaptic reflexes.
Finally, awake newborns do not show the slow rolling eye movements but they show rapid scanning eye movements and the typical eye-lid blinks.

The mechanisms underlying SEMs and REMs are still unknown. Structures involved either as the origin for their generation or as centres modulating their intensity and their frequency characteristics are situated in the pontine area, superior colliculi, midbrain and medial and descending vestibular nuclei; these are conclusions from animal studies mainly from experiments on adult cats (see Jouvet, 1967, and Pompeiano, 1967).

In the present study the effect of position on rapid and slow eye movements is investigated.

Qualitative results :

Newborns sitting in the baby-seat, as newborns lying in supine, did not show REMs and SEMs in state 1.
There existed one exception, however, at the occasion of a startle or a deep sigh a slow rolling eye movement could be observed. This event problaby resulted from a head movement that occurred with the startle or the sigh.
In the baby-seat in state 2, small head movements together with each breath were regularly observed. These head movements resulted in slow eye movements in a vertical or diagonal direction according to the relative head-to-body positions. Incidentally, the head movements do not only result in eye movements but also in opening and closing the eyes.
The question whether the eye-, and eyelid movements have a vestibular input or a neck-receptor input or a combination of both inputs as their origin can not be answered yet.

Quantitative results :

In the present study head position and changes in head position were not

restrained, since they were themselves topics for the study. This methodological decision resulted in an enormous inter- and intra-individual amount of variation in the relative head to body positions.
Too much detailed analyses of vertical and horizontal eye movements were therefore not possible, since not enough comparable situations were available. From a few more crude analyses, however, two results should be mentioned.
In all six newborns there were no REMs in state 1, neither in the baby-seat nor in the crib. This is a significant result at the 0.05 level.
From an analysis of the number of REMs per 3 minutes for all 3 minute epochs in state 2, no significant differences between the two positions were found. The mean and standard deviations for each infant are listed in table 5.2-16.

TABLE 5.2-16

Mean and standard deviations of the number of REMs per 3 minutes in state 2 (lying supine - horizontal - 0° - versus supine semi-upright - 60°-)

Baby	0°			60°	
	M.	SD		M.	SD
1900	20	(13)	<	39	(28)
1905	51	(13)	<	58	(19)
2519	35	(25)	>	30	(9)
1928	41	(7)	<	49	(26)
1953	45	(27)	<	48	(37)
2012	77	(29)	>	58	(20)
sign test			n.s.		

From the present data it seems that there is no strong effect of the position on the absolute number of REMs, but that spontaneously occurring head movements in state 2 and maybe in state 1 have an effect on the occurrence of slow eye movements.

5.2.2.7. *Discussion and comments on the comparison of postural behaviour of newborns in a supine horizontal and in a supine semi-upright position.*

The quantitative results can be grouped in results related to parameters that are affected by position and parameters that are not affected by position.
As to the behavioural state, babies are more and longer awake while sitting and this at the expense of the amount and the length of state 2 (state 1 is not affected).
The amount of gross-body movements in state 2 is higher in the 60°-position; this is mainly the result of an increase in the duration of such movements.
In the baby-seat the respiratory rate is higher in all behavioural states; the respiratory irregularity is greater in state 2 (but not in state 1).
In the baby-seat, in state 1, there are more sighs and the interval between the sighs is shorter.
In the baby-seat the heart rate is slightly higher. So far for the positive results.

Not affected by the position are the amount and the length of state 1, the number of the gross-body movements in state 2, the number of startles in state 1 and the amount of rapid eye movements in state 2.
It can thus be concluded that position in space has an effect on the behavioural state-cycle and on several physiological correlates of neonatal behaviour.

In how far these results should be considered as passive effects or as active reactions or adaptations is a more difficult question. However, for some findings active underlying mechanisms are very plausible. The increase in the respiratory rate is an adaptation to keep gas exchange per unit of time constant; since the volume per breath is mechanically reduced in sitting newborns. In state 3 and in state 1, when postural load increases, the respiration remains regular, this maybe due to the control of body posture and especially due to the control of the shape of the thoracic cage in these states. The baby seems furhter capable to optimize his respiration by changing the intervals of the sighs.
In state 2, both qualitatively and quantitatively, the gross-motor activities are very suggestive for being postural resets, possible also related to an optimalisation of breathing. Finally when postural load increases there is an increase in the awake states, the states that have a more active postural control as judged from our qualitative observations. There is a decrease in state 2, the state where the active posture seems to be at its lowest level. State 1, in which some degree of active posture seems to exist is not systematically affected.
These behavioural observations on postural control need further substantiation by hard facts (see loading experiments in section 5.4 and EMG recordings in section 5.5) before they can be accepted as the explanation for the present findings.

5.3. COMPARISON OF POSTURAL BEHAVIOUR OF NEWBORNS IN THE SUPINE HORIZONTAL AND IN THE PRONE HORIZONTAL POSITION

The next two experimental situations to be compared are two frequently used nursing positions. In the United States the predominant practice is to nurse the babies in prone, whereas in Europe babies are predominantly placed in supine (Brackbill et al. 1973).

Surprisingly little empirical research has been done so far to substantiate the effect of nursing positions on neonatal behavioural and on neonatal physiological variables.
Reisetbauer, 1968, Gleiss, 1969 and Mau, 1969, mention some twenty reasons why prone would be better than supine, they do not give any experimental support for their statements. Keitel et al., 1960, in a systematic study on positioning, showed that there was less diaper-rash and self-inflicted scratching in the prone as compared to the supine position, although skin-chafing occurred in both positions. Anders et al., 1971, in their instructions for neonatal sleep studies indicate the position as one of the parameters that should be controlled during a study and should be mentioned in the publication of the results. This is a methodological argument to enhance the uniformity and the consistency during a study and the comparability between studies.

Brackbill et al. (1973) concluded from experimental data that the prone position is superior for newborns, since newborns sleep more and cry less in the prone than in the supine position. Although the statement of these authors that the prone position is "the natural resting" position sounds very plausible and although their results are convincing, I doubt if their results can endorse their thesis. Thirty newborns were studied, all newborns were in the prone position until the experiment. This is not explicitly stated in the study, but it is obvious from the comments on nursery-customs in the United Stated, in their introduction. During the observations lasting two hours, fifteen newborns stayed in prone and fifteen newborns were turned over into a supine position, the study is actually a comparison between newborns that are confronted with a new position and newborns that stay in the familiar position.

In our obstetric nursery newborns were placed in the side position, right and left side alternated after every feed. In the present study both the prone and the supine position were new for the newborn.
The relative positions of the two vestibula in the field of gravity and of the head (containing the vestibula) in relation to the body are never identical in these two positions. If the inputs from the vestibula and from the neck-proprioceptive receptors play a role in neonatal postural behaviour then differences in those positions should be demonstrable.

5.3.1. Subjects and methods

Six newborns (group E' of table 2.1), with birth weights between the 25th and 90th percentiles, aged 4-5 days were the subjects for this behavioural and polygraphic study.
For reasons discussed in the previous section the experimental design was as follows :

1. All six newborns were in the side position before the experiment.
2. The number of positional changes was limited to two.
3. After the 1st feeding three babies started in the prone position, the three other babies in the supine position.
4. Halfway in each recording, the babies were changed from supine to prone or vice versa.

5. The time of the positonal changes coincided with the feeding sessions.
6. All recordings took place between 9 a.m. and 4 p.m.
Each baby was made his own control and therfore also in this section the sign test is used for the statistical analyses.

5.3.2. Predominant body postures and predominant head postures in the supine and in the prone position

The predominant postures described in this paragraph are those body and head postures that occurred during the highest percentage of the total observation time in a given position, excluding minutes in which the babies had gross-motor activities (see table 5.3-1)

TABLE 5.3-1

Body posture in the supine and in the prone position. (percentage of the total observation time in supine and in prone excluding the time during which the posture is unstable due to gross-motor activities)

Baby	Supine	Supine-R.	Prone	Prone-R.
2548	5	95	100	-
2644	52	48	100	-
2664	47	53	100	-
2544	100	-	100	-
2549	100	-	28	72
2665	51	49	100	-

- *Predominant body postures*

In supine four of the six babies had a predominant full supine posture. Two babies were predominantly on the right side (53 % and 95%). Two other newborns although predominantly in supine (52% and 51%) were still during a high percentage of time on their right side (48% and 49%)
In prone the picture was totally different; five of the six newborns remained in the prone position.
One baby after tilting his hips to the right side, remained in this prone, partly right-side position for the rest of the observation, i.e. for 72%.
In prone there was obviously less variation in body postures than in supine.

- *Predominant head postures*

The head posture was defined by the orientation of the face. The newborns were allowed to keep their face to the same side as to which they had turned it while being put down in prone.

In supine in five of the six newborns the predominant head posture was to the right; face to the left occurred once in 5 percent and once in 9 percent of the observation time (see table 5.3-2). In supine only one baby had a predominant face to the left posture, namely in 95 percent of the observation time.
In prone five of the six newborns had their face predominantly to the right side also. One baby in prone had in his face 100 percent of the observation

TABLE 5.3-2

Head posture in the supine and in the prone position (percentages of the total observation time in supine or in prone, excluding the time during which the posture is unstable due to gross-motor activities)

Baby	Supine				Prone		
	Face :	Left	Up	Right	Left	Down	Right
2548	-	5	-	95	100		
2644	-	-	-	100	9	-	91
2664	-	-	-	100	-	-	100
2544	-	95	-	5	-	-	100
2549	-	9	-	91	-	21	79
2665	-	-	-	100	-	-	100

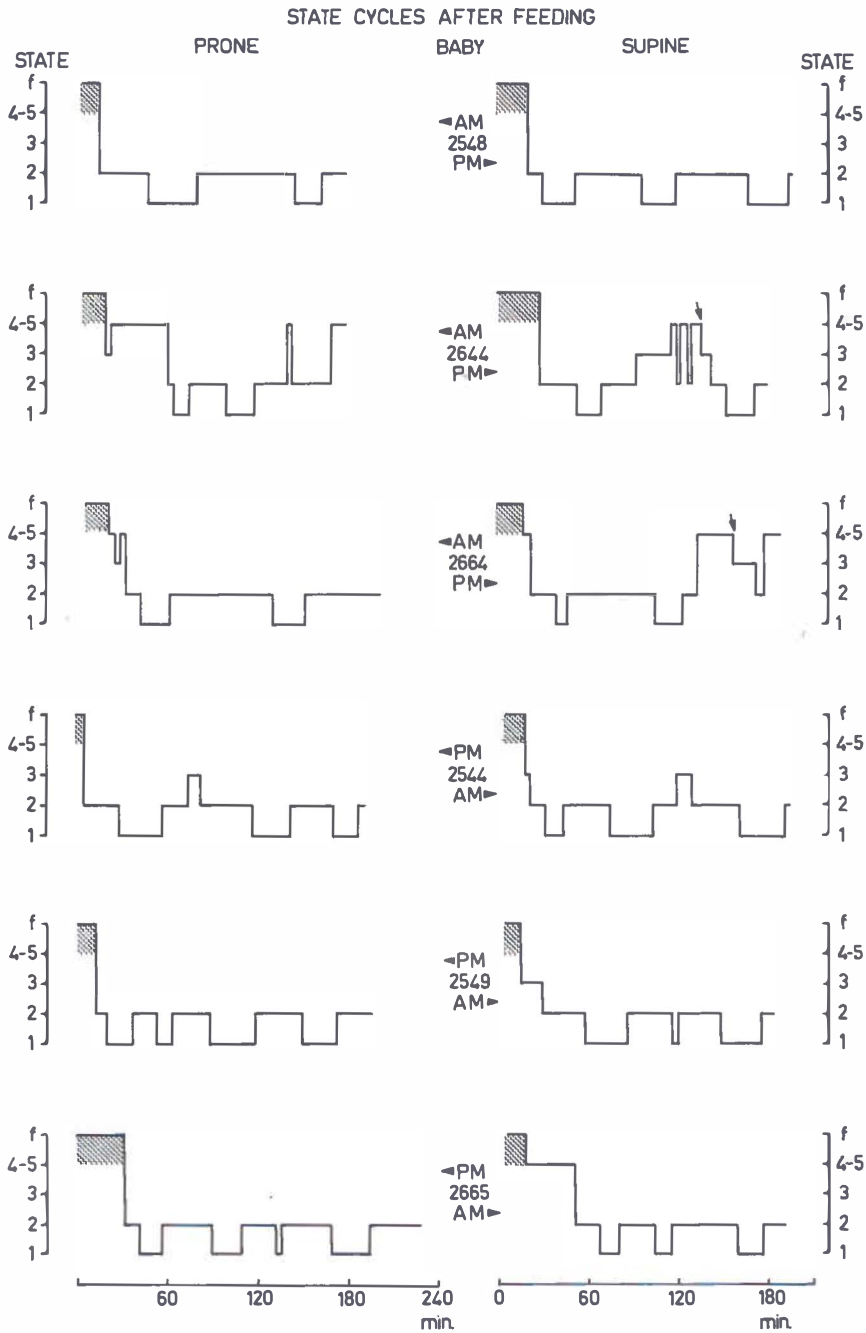
time to the left : this baby had in supine his face in only 5 percent to the left side. The baby whose face remained in 95 percent of the time to the left side in supine, had his face to the right in 100 percent of the time in the prone position. Finally, in one baby the face remained in full prone for about 21 percent of the observation time; first the nose was flat on the bed surface, later the face turned a little to the right and so the nostrils were more free.

The preference to the right for both the head and the body-posture in these newborns was striking, and is in agreement with findings in the literature. (see for a final discussion paragraph 6.3).
Furthermore, we were surprised that four of the six newborns in supine returned for 48% or more of the observation time into the previous side nursing position. The newborns in this group were not stabilized in the supine position, e.g., with some side rolls as it was done in the 0°-60° position study. This fact will make it more difficult to interpret some of the following quantitative results. But this same methodological decision made it possible to demonstrate that already in the perinatal period previous motor output programmes, such as previous postures may have an effect on ongoing postures and motor activities.

5.3.3. The behavioural states and the behavioural state cycle in the supine and in the prone position

When comparing postural behaviour in prone and in supine, using the same methods of analysis as in the comparison between supine lying and supine sitting newborns, no such consistent differences were found, neither in the percentages of time spent in the various states, nor in the duration of the behavioural states, nor in the longest sleep cycle, nor in the number of state transitions per hour in the two positions (see fig. 5.3-1 and tables 5.3-3, 5.3-4, 5.3-5, and 5.3-6).

The only systematic difference was that each baby was more in state 2 in prone; in two newborns (2644 and 2549), these differences however, were minimal namely one and two percent respectively (see table 5.3-3).
These results do not confirm the findings of Brackbill et al. (1973), stating that newborns sleep less in the supine position than in the prone position. However, only in the present study both experimental positions were new for the babies and therefore only this study, by its design, is



5.3. COMPARISON : SUPINE HORIZONTAL AND PRONE HORIZONTAL

TABLE 5.3-3

Percentage of time spent in each state
(Lying supine versus lying prone)

Baby	State 1			State 2			Awake (St. 3-4-5)		
	supine		prone	supine		prone	supine		prone
2548	40	>	31	60	<	69	0	=	0
2644	23	>	18	47	<	48	30	<	34
2664	15	<	23	53	<	71	32	>	6
2544	40	>	35	52	<	58	8	>	7
2549	35	<	41	57	<	59	8	>	0
2665	24	<	32	57	<	68	19	>	0
sign. test	n.s.			$p < 0.05$			n.s.		

TABLE 5.3-4

Mean duration of each state in minutes
(Lying supine versus lying prone)

Baby	State 1			State 2			Awake (St. 3-4-5)		
	supine		prone	supine		prone	supine		prone
2548	24	<	25	46	>	44	0	=	0
2644	17	>	14	16	<	24	14	>	13
2664	13	<	20	31	<	43	18	>	10*
2544	23	=	23	22	<	26	7*	=	7
2549	20	>	19	27	>	25	14*	>	0
2665	14	<	15	28	>	25	33*	>	0
sign. test	n.s.			n.s.			n.s.		

* only one value

Figure 5.3.-1. Behavioural state profiles of six newborns, aged 4-5 days, studied in supine and prone position.
- *The vertical scales indicate the behavioural states; "f" means feeding, the feeding period is crosshatched.*
- *The horizontal scale is time in minutes. In each position the origin of this scale is the onset of feeding.*
- *AM and PM indicate in which part of the day the baby remained in a particular position.*
- *Arrows on the profiles indicate when pacification was required for periods of crying lasting at least 3 minutes.*

TABLE 5.3-5

Longest sleep cycle in minutes
(Lying supine versus lying prone)

Baby	Supine		Prone
2548	71	>	64
2644	39	<	41
2664	77	<	89
2544	62	>	60
2549	58	<	62
2665	57	<	61
sign test		n.s.	

TABLE 5.3-6

The number of state transitions per hour
(lying supine versus lying prone)

Baby	Supine		Prone
2548	1.8	=	1.8
2644	3.5	<	3.7
2664	2.8	>	1.7
2544	3.1	>	2.8
2549	2.5	<	2.6
2665	2.6	>	2.5
sign test		n.s.	

related to the effects of two positions on neonatal postural behaviour. The actual outcome of the present study is not anymore a simple comparison between two positions, since four of the six newborns returned for a non negligable period of time into the right-side position. If newborns are more asleep in "familiar" postures, then this may (partly) explain the result of Brackbill et al. 1973, showing that the newborns in prone are less awake. This could also explain why in the present study the babies in supine were not more awake than in prone, since actually four of them returned for a considerable period in the side position, which was their previous nursing position.

5.3.4. Gross-motor activities in the supine and in the prone position

If gross-body movements in state 2 are postural readjustments then we would expect more gross-motor activities in the less stable supine position than in the prone position. Therefore, the questions to be answered are :
are there more body movements in the supine than in the prone lying babies?
are the durations of the gross-body movements longer in the supine position?
are the intervals between gross-body movements shorter in the supine than in the prone position?
Like in the comparison between the sitting and the lying newborns, the polygrams were visually analysed and those seconds in which at least 3 out of 4 muscles were active were accepted as gross-motor activity.

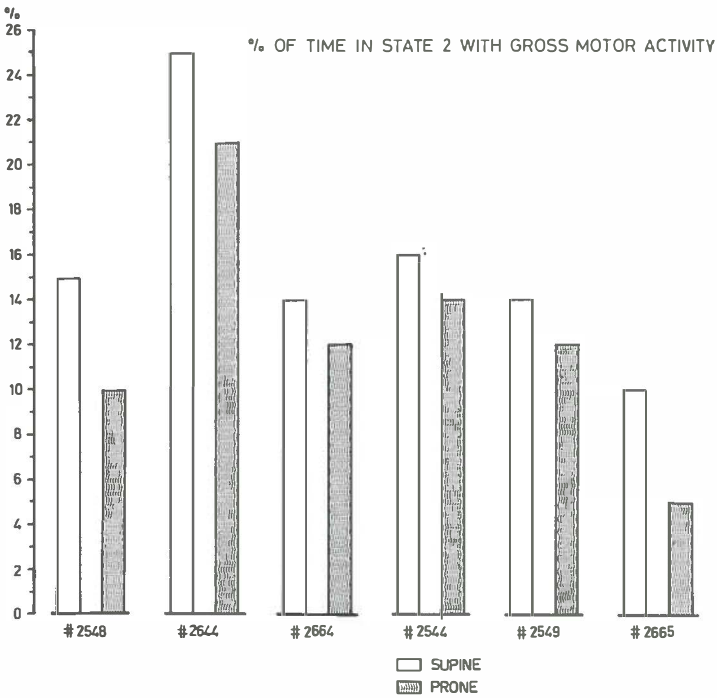


Figure 5.3.-2. Percentage of time in state 2 with gross-motor activity. In each baby the percentages of time in state 2, in which three out of four EMG recordings showed muscle activity, are compared in the supine and in the prone position.

TABLE 5.3-7

Time with gross-motor activity as a percentage of total time spent in state 2 (lying supine versus lying prone)

Baby	Supine		Prone
2548	15	>	10
2644	25	>	21
2664	14	>	12
2544	16	>	14
2549	14	>	12
2665	10	>	5
sign test		$p > 0.05$	

TABLE 5.3-8

Mean duration in seconds of gross-motor activities in state 2 (lying supine versus lying prone)

Baby	Supine		Prone
2548	27	>	16
2644	35	<	43
2664	31	>	23
2544	35	>	31
2549	17	>	15
2665	17	>	10
sign test		n.s.	

TABLE 5.3-9

Mean interval in seconds between two onsets of gross-motor activities in state 2 (lying supine versus lying prone)

Baby	Supine		Prone
2548	139	<	172
2644	191	<	265
2664	197	>	178
2544	252	>	197
2549	156	<	169
2665	131	<	240
sign test		n.s.	

From figure 5.3-2 and table 5.3-7 it is clear that the newborns in the supine position showed more gross-motor activities than in the prone position. From table 5.3 -8 it appears that part of the explanation is that movements lasted longer in supine. Baby 2644 was an exception. This baby had in prone four head-lifts lasting longer than two seconds and furthermore fifteen head-lifts lasting shorter than two seconds. The head-lifts, a behavioural category present in prone and not in supine, will be discussed below.
In table 5.3-9 the intervals between gross-motor activities are displayed; these results do not show significant differences.

When comparing the individual findings on gross-motor activities (in figure 5.3-2 and from table 5.3-7 and 5.3-8) with the percentages of the observation time during which each newborn remained in prone, supine or on the right-side (see table 5.3-1) no clear relations are seen.
This should not be surprising, since for the amount and the length of gross-motor activities it is not so relevant what the basic position is, as how hard a newborn tries to get into such a position and how well the newborn is supported in a given position; e.g., the side position can be either a very comfortable resting position or a continuous threat of rolling forwards or backwards.

Head-lifts in the prone position

Newborns asleep in prone in state 2 showed occasionally head-lifts. In chapter 4 the qualitative aspects of these head-lifts have been described. They can be divided in head-lifts lasting two seconds or longer (head-lift ++), in head-lifts shorter than two seconds (head-lifts +) and in unsuccessful attempts to lift the head (head-lift ±).

TABLE 5.3-10

Total number of head-lifts during the observation in the prone position in state 2

Baby	++	+	±
2548	0	1	4
2644	4	15	13
2664	0	2	8
2544	0	6	4
2549	0	2	0
2665	0	1	1

In table 5.3-10 for each baby the numbers of the various types of head-lifts in the prone position in state 2 are listed. All six newborns had head-lifts in state 2. Interindividual differences in the number and in the intensity of the head-lifts were large, baby 2644 showed the most active head-lifts with 19 successful and 13 attemptive head-lifts; baby 2665 showed only one head-lift (+) and made only one attempt.
As stated previously baby 2644 showed a longer mean duration of gross-motor activities in prone than in supine; speculatively this fact may be related to the high number and the strong intensity of head-lifts in this particular baby. To test this assumption, for all six babies, the mean duration of the gross-motor activities in those state 2's, in which head-lifts occurred were compared with the mean durations in those state 2's without head-lifts. The results of this analysis, listed in table 5.3-11 suggest strongly that the above assumption is correct, since gross-body movements lasted longer in states 2 with head-lifts.

TABLE 5.3-11

Mean duration (in seconds) of gross-motor activities in states 2 with head-lifts and in states 2 without head-lifts

Baby	with head-lifts	without head-lifts
2548	17	14
2644	51	19
2664	23	does not occur
2544	37	19
2549	20	7
2665	11	8

Do active babies lift their heads more often ? Or are head-lifts such unique phenomena that other motor activities can be triggered or prolonged as a result of them ? By comparing the number of successful head-lifts per baby (see head-lifts ++ and + in Table 5.3 -10) with the percentage of state 2 time with gross-motor activity (see fig. 5.3-2 and table 5.3-7) it can be seen that baby 2644 and baby 2544 had the most numerous successful head-lifts and that they showed the highest percentage of gross-motor activities in prone, but also in supine ! Although the number of observations is very small, it seems that newborns who are active during sleep lift their heads more often.

During this analysis it became also clear that the states 2 without head-lifts were in all five babies the first states 2 after falling asleep, in baby 2665 even both the first and the second state 2 had no head-lifts. This finding, although it needs further confirmation, in intriguing, since it suggests a difference between the first state 2 after sleep onset and the subsequent states 2.

Finally, the qualitative impression that head-lifts are frequently accompanied by vocalization could not be confirmed in these six newborns. Vocalization during sleep seemed more an individual characteristic, since babies vocalizing in prone at the occasion of head-lifts vocalized also in supine during gross-body movements.

The startles

Comparing the number of startles in state 1 in the prone and in the supine position, no consistent differences between the two positions were observed (see table 5.3-12 and 5.3-13); in the cases where the number of startles in a newborn was higher than five startles per state, the highest number was always seen in the supine position; this happened in three babies in state 2 and in two babies in state 1.
Observing startles in prone, however, was more difficult than in supine, since a startle in prone was frequently only a sudden stirring movement of the baby. Therefore a new study with the improved surface electromyography would be interesting to elaborate on this problem.

TABLE 5.3-12

Total number of startles in state 2 during the observation and in brackets the maximum number of startles per state (lying supine versus prone).

Baby	Supine		Prone
2548	2(2)	>	2(1)
2644	9(5)	>	1
2664	5(3)	>	3(2)
2544	2(1)	=	2(1)
2549	11(4)	>	3(1)
2665	15(8)	>	3(1)
sign test		n.s.	

TABLE 5.3-13

Total number of startles in state 1 during the observation and in brackets the maximum number per state (lying supine versus lying prone)

Baby	Supine		Prone
2548	3(2)	<	4(4)
2644	9(7)	>	1
2664	3(3)	<	5(3)
2544	2(1)	>	0
2549	5(3)	>	3(3)
2665	13(8)	>	12(6)
sign test		n.s.	

5.3.5. Respiration in the supine and in prone position

From the observations of postural behaviour of newborns lying in prone and in supine position it was obvious that the differences in breathing were much smaller between these two positions than the differences observed between the babies lying supine horizontal and sitting in the baby-seat. Differences in the regularity of the respiration between state 1 and state 2 were the easiest to be seen in the supine position, and less easy in the prone and in the side position.
Using the same techniques of analysis as in the comparison between the lying and the sitting newborns, the respiratory rate, its regularity and the sighs, were studied in the prone and in the supine position.

Respiratory rate :

Comparing the mean values of the 50th percentiles of the breath-breath interval distributions of all 3 minutes-epochs in the prone and in the supine position, no systematic differences were seen (see table 5.3-14). In table 5.3-15 the corresponding frequencies of these values are listed. Splitting up these data in state 1 values and in state 2 values does not bring any significant differences between the two basic positions.

TABLE 5.3-14

Respiratory rate : mean in milliseconds of the 50th percentiles of breath-breath interval distributions in all 3' epochs in the prone and supine position

Baby	State 1			State 2			Total observation		
	Prone		Supine	Prone		Supine	Prone		Supine
2548	1493	<	1497	1225	>	1149	1359	>	1265
2644	926	<	1069	919	<	966	862	<	977
2664	1271	<	1301	1216	>	1124	1260	>	1226
2544	1807	>	1640	1425	>	1301	1526	>	1383
2549	1594	>	1440	1598	>	1460	1596	>	1449
2665	1614	<	1636	1309	>	1235	1318	<	1462
sign test		n.s.			n.s.			n.s.	

TABLE 5.3-15

Corresponding respiratory frequencies per minute in the prone and supine position

Baby	State 1			State 2			Total observation		
	Prone		Supine	Prone		Supine	Prone		Supine
2548	40	=	40	49	<	52	44	<	47
2644	65	>	56	65	>	62	70	>	61
2664	47	>	46	49	<	53	48	<	49
2544	33	<	37	42	<	46	39	<	43
2549	38	<	42	38	<	41	38	<	41
2665	37	=	37	46	<	49	46	>	41
sign test		n.s.			n.s.			n.s.	

TABLE 5.3-16

Respiratory rate : mean in milliseconds of the 50th percentiles of breath-breath-interval distributions in all 3' epochs and the corresponding frequencies

State 1

Baby	Prone	Prone + Side	Supine	Side
2548	1493	-	-	1497
	40	-	-	40
2644	1271	-	-	1301
	47	-	-	46
2664	926	-	-	1069
	65	-	-	56
2544	1807	-	1640	-
	33	-	37	
2549	1770	1418	1440	-
	34	42	42	-
2665	1614	-	1582	1690
	37	-	38	36

State 2

Baby	Prone	Prone + Side	Supine	Side
2548	1225	-	975	1322
	49	-	62	45
2644	1216	-	1091	1157
	49	-	55	52
2664	919	-	924	1007
	65	-	65	60
2544	1465	-	1301	-
	42	-	46	-
2549	1776	1419	1460	-
	34	42	41	-
2665	1309	-	1204	1265
	46	-	50	47

Four babies, however, spent more than 40% of the observation time in a right-side position instead of a full supine position. Therefore in a next comparison the 3 minutes-values were divided in values derived in the prone, the prone-side, the supine and the right-side position. The mean values and their corresponding frequencies are listed in table 5.3-16 for state 1 and state 2 separately.
In state 1 there was no considerable effect of the position on the respiratory rate. In state 2, however, five babies in the full-supine had a higher respiratory rate than in the prone position, one baby showed equal values (2664). In the supine position the respiratory rate was also higher than in the side position, this comparison was, however, only possible in four babies. One baby (2549) was in the prone partly-side position; in this situation his respiratory rate was higher than in the prone position. From these results it looks thus that newborns in state 2 breath faster after they are placed in a supine position than after they are placed in a prone position.

Respiratory regularity :

As an estimate for the irregularity of the respiration, like in the comparison between sitting and lying newborns, the ratios between the means of the interquartile ranges and the means of the 50th percentiles of all breath-breath interval distributions in a given position were calculated; they are listed in table 5.3-17 for state 1 and for state 2 separately.

TABLE 5.3-17

Respiratory regularity : ratios of the averaged interquartile ranges to the averaged fiftieth percentiles of breath-breath intervals of all 3 minutes epochs

State 1

Baby	Prone	Prone + Side	Supine	Side
2548	.17	-	-	.13
2644	.15	-	-	.18
2664	.16	-	-	.19
2544	.11	-	.10	-
2549	.15	.18	.17	-
2665	.16	-	.27	.19

State 2

Baby	Prone	Prone + Side	Supine	Side
2548	.31	-	.71	.31
2644	.26	-	.37	.31
2664	.45	-	.55	.39
2544	.34	-	.37	-
2549	.20	.45	.37	-
2665	.33	-	.46	.45

In state 1 differences between ratios were minimal, no effect of position could be observed. In state 2 again all six babies had a higher ratio, i.e. they breathed more irregularly in the supine position than in the prone position. The one baby (2549) in prone whose pelvis and legs were twisted to the right-side, had also a higher ratio in this position than in the prone position.

These results, like the results in the comparison between the sitting and lying babies, demonstrate that the newborn was capable to keep his respiration relatively regular in different positions in state 1.
In state 2 the supine position looked the most stressful, but when babies lying in supine turned over in a side position, the respiratory regularity was more comparable with the respiratory regularity in the prone position.

Is the sigh a reset in respiration and postural control?

From the comparison between sitting and lying newborns the sigh seemed to be a reset phenomenon to optimize breathing. The number of sighs was higher, the intervals between sighs were shorter when postural load was high, i.e. in the sitting babies.
Therefore also in the present comparison between babies lying in prone and in supine the sigh was studied, using the same methods of analysis as in the previous comparison.

No systematic differences were found between the babies lying in prone or in supine, neither in the intervals between two sighs nor in the number of the sighs per 10 minutes (see tables 5.3-18 and 5.3-19).

TABLE 5.3-18

Mean (in seconds) of the intervals between two sighs in state 1 (lying supine versus lying prone)

Baby	Supine		Prone
2548	425	<	480
2644	245	>	242
2664	232	=	232
2544	280	<	291
2549	235	<	251
2665	139	>	135
sign test		n.s.	

TABLE 5.3-19

Number of the sighs per 10 minutes in state 1 (lying supine versus lying prone)

Baby	Supine		Prone
2548	1.3	<	1.5
2644	2.5	<	3.
2664	5.8	>	2.5
2544	2.7	>	2.2
2549	1.8	<	2.5
2665	2.	<	4.
sign test		n.s.	

In prone, two newborns showed more sighs in the second half than in the first half of state 1, two newborns had equal numbers, and two newborns had more sighs in the first half of state 1. In the supine position, in this sample, all six newborns had more sighs in the second half of state 1; this is a significant finding at the 0.05 level (sign test). The absolute numbers of sights per baby and per position or per subposition were too small to derive meaningful conclusions from this results or from further analyses such as interval histograms.

5.3.6. Heart rate in the supine and in the prone position

In the comparison between sitting and lying newborns no clear differences in heart rate and in heart-rate regularity were found in the two positions. Dahl and Välimäki (1972) Brackbill et al. (1973) did not find any differences in the heart rate between babies lying in the prone and lying in the supine position.

TABLE 5.3-20

Heart rate : mean in milliseconds of the 50th percentiles of heart - beat-interval distributions of all 3'epochs in the prone and supine position

Baby	State 1			State 2			Total observation		
	Prone		Supine	Prone		Supine	Prone		Supine
2548	541	>	480	505	>	453	525	>	464
2644	481	<	505	443	<	460	453	>	449
2664	415	<	445	426	>	423	413	<	424
2544	467	<	476	426	<	439	439	<	443
2549	532	<	558	510	<	524	521	<	540
2665	532	<	644	449	<	560	491	<	583
sign test		n.s.			n.s.			n.s.	

TABLE 5.3-21

Heart rate : Corresponding frequencies in the prone and in supine positions

Baby	State 1			State 2			Total recording		
	Prone		Supine	Prone		Supine	Prone		Supine
2548	111	<	125	119	<	132	114	<	129
2644	128	>	119	135	>	130	132	<	134
2664	145	>	135	141	<	142	145	>	142
2544	128	>	126	141	>	136	137	>	135
2549	113	>	108	118	>	115	115	>	111
2665	113	>	93	134	>	107	122	>	103
Sign test		n.s.			n.s.			n.s.	

Heart rate

Using the same methods of analysis as in the previous section, the means of the 50th percentiles of the heart-beat interval distributions of all 3 minutes-epochs in the prone and in the supine position were calculated, they are listed in table 5.3-20, the corresponding frequencies are listed in table 5.3-21
Comparing the heart rate in the newborns in prone with those in supine no systematic differences were seen ; therefore these values were also grouped according to the subpositions i.e. prone, prone-side, supine and right-side position, they are listed in table 5.3 -22.

TABLE 5.3-22

Heart rate : mean in milliseconds of the 50th percentiles of heart-beat intervals distributions in all 3'epochs, and the corresponding frequencies

State 1

Baby	Prone	Prone+Side	Supine	R. Side
2548	541	-	-	480
	111	-	-	125
2644	481	-	-	505
	125	-	-	119
2664	415	-	-	445
	145	-	-	135
2544	467	-	476	-
	128	-	126	-
2549	518	546	558	-
	116	110	108	-
2665	532	-	647	640
	113	-	93	94
sign test				
				State 2
2548	505	-	457	454
	119	-	131	132
2644	443	-	429	492
	135	-	140	122
2664	426	-	411	434
	141	-	146	138
2544	426	-	439	-
	141	-	137	-
2549	528	492	524	-
	114	122	125	-
2665	449	-	584	537
	134	-	103	112

From this comparison only one relatively consistent relation between position and heart rate could be seen, namely five out of six newborns showed a faster heart rate in state 1 in the prone position.

Heart rate regularity

The ratios between the 50th percentiles and the interquartile ranges of the heart-beat interval distributions of all three minutes-epochs in each of the four positions were calculated and listed in table 5.3-23.

TABLE 5.3-23

Heart rate regularity : ratios of the averaged interquartile ranges to the averaged fiftieth percentiles of heart-beat intervals of all 3 minutes epochs in

Baby	Prone	Prone+Side	Supine	R. Side
				State 1
2548	.08	-	-	.07
2644	.07	-	-	.08
2664	.02	-	-	.03
2544	.06	-	.07	-
2549	.05	.06	.04	-
2665	.08	-	.17	.12
				State 2
2548	.12	-	.13	.14
2644	.16	-	.18	.15
2664	.07	-	.07	.09
2544	.08	-	.11	-
2549	.06	.10	.12	-
2665	.09	-	.23	.13

In state 1 no systematic relation between positions and heart-rate regularity was seen. In state 2 five out of six newborns had a more irregular heart-rate in the supine position. The heart rate irregularity in the side position showed no systematic differences with the heart rate regularity in the two other positions.

From these findings one result needs a further comment, namely the higher heart-rate in state 1 in the prone position, which existed in 5 out of 6 newborns. This may be related to the increased effort performed by the respiratory muscles in the prone position. This increased effort would be necessary for the thoracic-cage movements which are larger in the prone than in the supine position, as it was demonstrated, using impedance pneumography, by Dahl and Välimäki (1972) : their observation however was made in periods with regular respiration in awake newborns (state 3) and not in periods with regular respiration during sleep (state 1).

5.3.7. Eye movements in the supine and in the prone position

Since the input from the vestibula and the neck receptors are qualitatively different in the prone and in the supine position and since the input is more variable in supine the number of REMs in the two positions has been studied. In all six newborns no REMs have been observed in state 1. From an analysis of the number of REMs (per 3 minutes) during state 2, in the prone and in the supine position, no significant differences were found. The mean and the standard deviations of each infant are listed in table 5.3-24

TABLE 5.3-24

Mean and standard deviations of the number of REMs per 3 minutes in state 2 (lying supine versus lying prone)

Baby	Supine		Prone
2548	37 (19)	<	38 (20)
2644	37 (33)	=	37 (16)
2664	30 (23)	<	33 (20)
2544	53 (21)	>	46 (16)
2549	31 (22)	<	55 (32)
2665	25 (14)	>	20 (16)
sign test		n.s.	

Thus also in this comparison, as in the comparison between sitting and lying newborns, no effect of the position on the number of REMs could be demonstrated.

5.3.8. Discussion and comments on the comparison of postural behaviour of newborns in the supine horizontal and in the prone horizontal position

The most intriguing result from this section is the finding that four out of six newborns after being placed in the supine position turned over in a side position, which was their previous nursing position. Related to this result is the observed head-preference to the right in both the prone and in the supine position.
Intrauterine position and previous nursing position are both factors which may have influenced these findings ; their relative importance can not be evaluated from this series. (see further paragraph 6.3)

The further results will be discussed in an attempt to answer the question are there differences in neonatal behaviour in newborns after they are placed in the prone or in the supine position ?
The amount of gross-body movements was higher in the supine than in the prone position ; this was mainly due to the increased duration of the gross-body movements in the supine position. In supine the movements have a role in the stabilisation of the posture ; in prone the amplitude of the movements is more restricted since the weight of the baby is more bearing on the extremities. In prone a unique gross-body movement existed namely the head-lifts.
The startles in state 1 were behaviourally quite different in these two positions ; in prone they looked like a sudden stirring movement of the baby and they were not like the large amplitude, short-lasting movements that could be observed in the supine position.

From the comparison between babies sitting and lying the sighs appeared as a reset in respiratory and postural control, they increased in amount and in their frequency of occurrence when postural load increased, namely in the sitting newborns ; therefore it was interesting to see the equal distribution of the sighs in the prone and in the supine position. Looking to respiratory rate and regularity it was necessary to subdivide the results in four groups : namely the prone, the prone-side, the supine, and the side position, before an effect of the position could be demonstrated. In state 2 the respiration was faster and more irregular in the supine position than in the prone position and also than in the side position, this last comparison, however, was only based on four observations.
Finally, the heart rate in state 1 was higher in prone in five out of six newborns.

So far the positive results. The negative results from this comparison between prone and supine can be briefly recapitulated. There were no differences in the amounts and the durations of wakefulness and of state 1. In supine all six babies had a little less state 2 ; in two babies, however, the differences were only 1 and 2 percent respectively. Therefore, I hesitate to consider this result as a further argument that the amount of state 2 decreases when postural load increases, as it was clearly demonstrated in the sitting newborns in the previous comparison.
No differences were found either in the intervals between gross-body movements in state 2, or in the occurrence of the startles in state 1 or in the number of the REMs in state 2.

From these results some remarks can be made as to question : which position should be considered as the optimal nursing position? Normal newborns looked comfortable in each of the studied positions, and they showed qualitatively and quantitatively different postural behaviour in the studied positions. Therefore, I think that normal newborns may profit most from a nursing schedule in which the position is regularly changed. In abnormal infants the decision should be based on an analysis of the main problem of a particular newborn, e.g. hyperexcitable babies might profit from the stable prone position whereas newborns with a neck extensor muscle hypertonia should be better placed in a side and not in a prone position to avoid too frequent and too intensive head-lifts. Further experiments focusing on neonatal behaviour especially on postural behaviour should not only take into account the position in which newborns are placed but they should consider the actual orientation in which the baby remains.

5.4. POSTURAL REACTIONS TO IMPOSED POSITIONAL CHANGES

From the results obtained so far it is difficult to conclude whether the stability of posture in state 1 is due to a smaller amount of episodic phenomena in this state or is due to an actively controlled phenomenon. Favouring an actively controlled posture are : the absolute regularity of the respiration which remains regular in all orientations studied, the qualitative observation that in state 1 after a startle the baby's posture does almost not change and finally the fact that state 1 seems not to be affected (either in its duration or in the percentage of time of its occurence during an observation) by the positions so far imposed.
To test the hypothesis that the stability of the posture in state 1 is an active process, differences should be demonstrated in postural responses between state 1 and the epochs without gross-body movements in state 2. Therefore the postural system should be loaded in a gradual, gentle and reproducible manner in the various behavioural states. For this purpose, and since newborns in their daily life are carried and gently rocked by their mothers, it was decided to construct an apparatus that would enable us to rock a baby either about its transverse or about its longitudinal axis. During these rocking movements posture and postural reactions of newborns in the different behaviour states were studied.

5.4.1. Experiments with rocking of the infant about a transverse axis

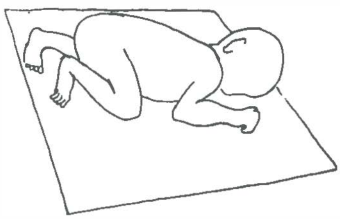
5.4.1.1. *Subjects and methods*

Seven newborns (group F of table 2.1), with birth weights between the 25th and 90th percentiles, aged 4 to 8 days, were studied. The observation took place in the morning, and lasted two to four hours.
The newborns were placed on the smooth platform of the rocking table, where they were rocked around their mid-thoracic transverse axis. The rocking table will be described in the following paragraph, since for the present rocking experiments it is only relevant to know that the table is constructed in such a manner that the axis of rotation was projected through the body, and not through the supporting platform, a pure rotation was thus imposed on the newborn, and not also a translation of his centre of gravity.
During these observations the physiological state parameters were recorded on the polygram and in the last baby studied, a series of photos was made of those postures and postural reactions that were considered as characteristic out of the six previous observations. The drawings that illustrate this section are derived from these photos.
During the first three observations various frequencies and amplitudes, and continuous versus discontinuous rocking were tried. For the next four experiments we decided to rock the babies continuously with a frequency of 0.3 Hz and a maximum amplitude of 20 degrees.

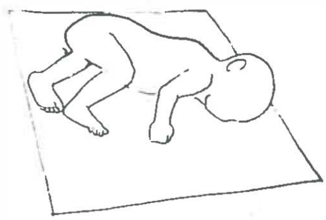
5.4.1.2. *Results*

In state 3, i.e. the quiet awake state, during the rocking no displacements of the infant on the platform were observed. There were small movements of the head, and changes in the angles of the elbows, the hips, the knees and the feet. In state 4 the newborns lifted their heads regularly and they crawled, making it difficult to continue the rocking in state 4. Head-lifts were so intense that we feared too strong head-bouncing on the table and we regularly had to intervene during these active awake periods.
Once asleep in state 2 the newborns glided passively forwards and backwards

over the supporting surface. This gliding was more obvious in the second and later states 2, than in the first state 2 after the onset of sleep. About 70 percent of the number of rocking movements, observed in state 2 in these four newborns, resulted in displacements ranging from 4 to 10 centimeters; in about 5 percent no displacements were observed in state 2, but in 25 percent large displacements ranging from 10 to 35 centimeters occurred. During these large displacements the newborns reacted with gross-body movements, with head-lifts, with crawling and with rolling over to the side; three out of the four babies ended up in such a side posture during the observations.



State 1



State 2

During gross-body movements in state 2 newborns attempted to readjust their posture. If these attempts were not successful the newborns arrived in odd postures. On such occasions newborns started fussing and the observer had to intervene to readjust the baby on the table. This intervention was occasionally also necessary to prevent the newborns in state 2 from sliding off the table.
In state 1, as in state 3, the babies maintained their postion on the table. The displacements in state 1 were zero most of the time; in about fifteen to twenty percent of the number of rocking movements observed in state 1 a small displacement was seen, ranging from 2 to 4 centimeters; in one baby after a jerk in state 1 a displacement of 6 centimeters was observed. Also in state 1 small changes in the neck-, shoulder-, elbow-, hip-, knee- and ankle angles occurred at each tilt; the consistency over time of such changes was remarkable. Finally, in the 7 newborns studied it was never necessary for the observer to intervene during a state 1 or a state 3.

5.4.1.3. *Discussion and comments on the experiments with rocking about a transverse axis*

From these experiments evidence is obtained that in state 1 there is an actively controlled posture, that the baby in state 2 either does not react at all, or during a gross-body movement he reacts, tries to readjust and if he is not successful he awakes.
Newborns seem to use different strategies to control their body postures during imposed positional changes.
From the various postural loads used in the present study, the rocking experiment about a transversal axis is the most appropriate. The stimulus is gentle and the baby has still enough freedom to show a more or less natural behavioural repertoire. What remains to be done, however, is to correlate the postural behaviour (if possible documented with time-lapse photography) with electromyographic activities recorded with the improved surface electromyography.

5.4.2. Experiments with rocking of the infant around a longitudinal axis

The crucial role of the neck muscles in body posture is their controlling of the position of the head in space. A specific head position can, however, be achieved with different body positions. Changes in the head-to-body relationship are perceived by the neck proprioceptive receptors. Hence, neck muscles together with their tendons and with the neck joints are besides very refined tools for motor output functions, also a very precise proprioceptive sensory input unit in the postural system as a whole. Observations made while repeating the experiments of Von Bernuth and Prechtl (1969) on the vestibulo-ocular response provided the immediate impetus to study in detail this dual neck function and the changes in its control. Von Bernuth and Prechtl (1969) demonstrated that the eye movement response to continuous sinusoidal rocking about the longitudinal axis, as expressed in the electro-oculogram, was of high amplitude during wakefulness and state 2 and was markedly diminished or absent during state 1. The phase-angle between the sinusoidal stimulus and the EOG response was approximately 180° in wakefulness and irregular sleep, but it was always larger in regular sleep. In these original experiments the babies were lying on a rocking table, head and body on the same supporting surface, the head was stabilized within a head-fixator on the board. This ensured that the head-body axis stayed the same during the observations. The stimulus applied was a translation.
Repeating this experiment (n=3 newborns, group G, see table 2.1), using the same experimental method as Von Bernuth and Prechtl (1969), we observed small changes of the head position in the head-fixator; these changes were state related, there was more variation in the head positions in the awake states and in state 2 than in state 1.
Therefore, the head-fixator was removed, and the effect of longitudinal rocking on the unrestrained head was observed. The unrestrained head, however, mostly fell to the side. It was only when the babies were actively awake, or awake and non-nutritive sucking on a nipple, that the face was more or less upwards in the midline. In that condition (with the head lying on the same platform as the body) when the platform was tilted to the right side, the head followed first a few degrees to the right side, then the head returned to the opposite direction sometimes with a rather brisk movement, and finally the head rolled in the same direction as the imposed movement. This small head-turn against the direction of the imposed movements was already described by Zador (1938). Zador filmed the reactions of a few two weeks old infants during sudden and slow movements of a supporting platform to the right or to the left. Besides the short head-turn against the imposed movement, Zador also demonstrated that the young infants changed their arm posture, the infants brought their hands very close to their face as soon as the table turned to the side (Zador, 1938).
From these observations we decided to study in more detail this head-body-transfer controlled by the neck muscles. The experimental design was as follows : a rotation was imposed on the body and the manner in which the head followed this rotation in various behavioural states was studied by supporting the head in a head-holder, which was not fixed to the platform.

5.4.2.1. *Technical note : the rocking table and the head-holder*

The apparatus consists of two parts : the rocking table and the head-holder. These parts can be used either separately or in combination.
Before designing such an apparatus a few anatomical data should be known. They are listed in table 5.4-1.

TABLE 5.4-1

Neonatal measurements, relevant for the construction of the rocking table and the head-holder. (cm)

Crown-heel length	51.2	°°°
Crown-rump length	32	°°°
Crown-Manubrium Sterni Length	13	°°
Head-circumference	35.1	°°°
Chest-circumference	33.4	°°°
Biparietal diameter-head	9.5	°
Biparietal diameter-thorax	10	°°
Biparietal diameter-abdomen	12	°°
Occipito-frontal diameter head	12	°°
Height of the body	12	°°

Ref. : Campbell, 1969°, Crelin, 1969°°, Usher and McLean°°°, 1969.

These data are derived from studies by Usher and McLean (1969) and by Campbell (1969); from both these studies the means are listed in table 5.4-1. To our knowledge some measurements, important for the present problem, have not been measured systematically in larger groups of newborns; therefore we derived them from drawings on scale in the "Anatomy of the newborn", an atlas by Crelin (1969). From these data it can be seen that a container for the head including the neck should measure approximately 10 x 12 x 13 cm; the container for the body should be more like 12 x 12 x 50 cm.
Another relevant factor is the location of the centre of gravity. For a newborn lying in supine there is relatively more weight in the lower layers of the head and the body. The brain and the skull are heavier than the facial skeleton; the vetrebral column with the paravertebral muscles and several of the internal organs, situated in the lower layers, are heavier then the upper parts of the thoracic cage with the lungs, and the upper layers of the abdomen with the gastrointestinal tract. The axis of rotation through the centre of gravity of head and body should thus be projected relatively close to the supporting surfaces.

The rocking table

For our experimental design the following requirements can be specified for the rocking table :
The imposed movement should be sinusoidal.
The axis of rotation should be projected as close as possible through the centre of gravity.
The amplitude and the frequency of the sinusoidal rotation should be adaptable. The movement should be either continuous or discontinuous
The body should remain as close as possible to a position symmetric with respect to the axis of rotation
The imposed movement should be registrated.
A general view of the rocking-talbe is given in figure 5.4-1 and an exploded view is available in figure 5.4-2.

The following specifications of the apparatus attempt to fulfil the requirements :
The suspension of the supporting platform is situated 5 cm above the supporting platform, thus the axis of rotation projects through the body of the newborn and the imposed movement of the body is a sinusoidal rotation.

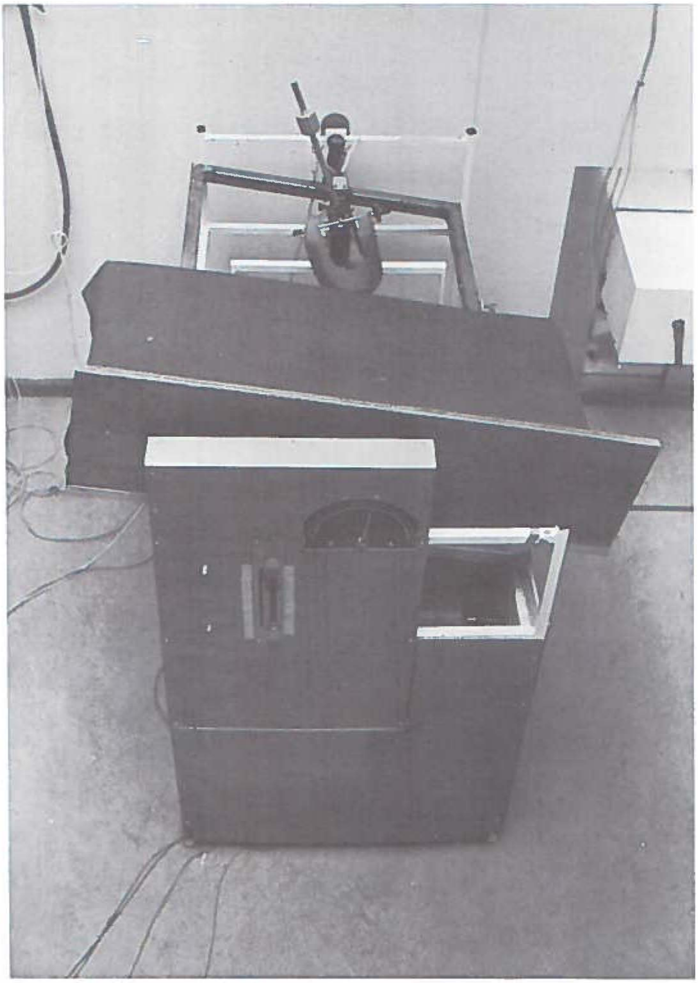


Figure 5.4.-1. The rocking table with the head-holder (compare with figures 5.4.-2 and 5.4.-3).

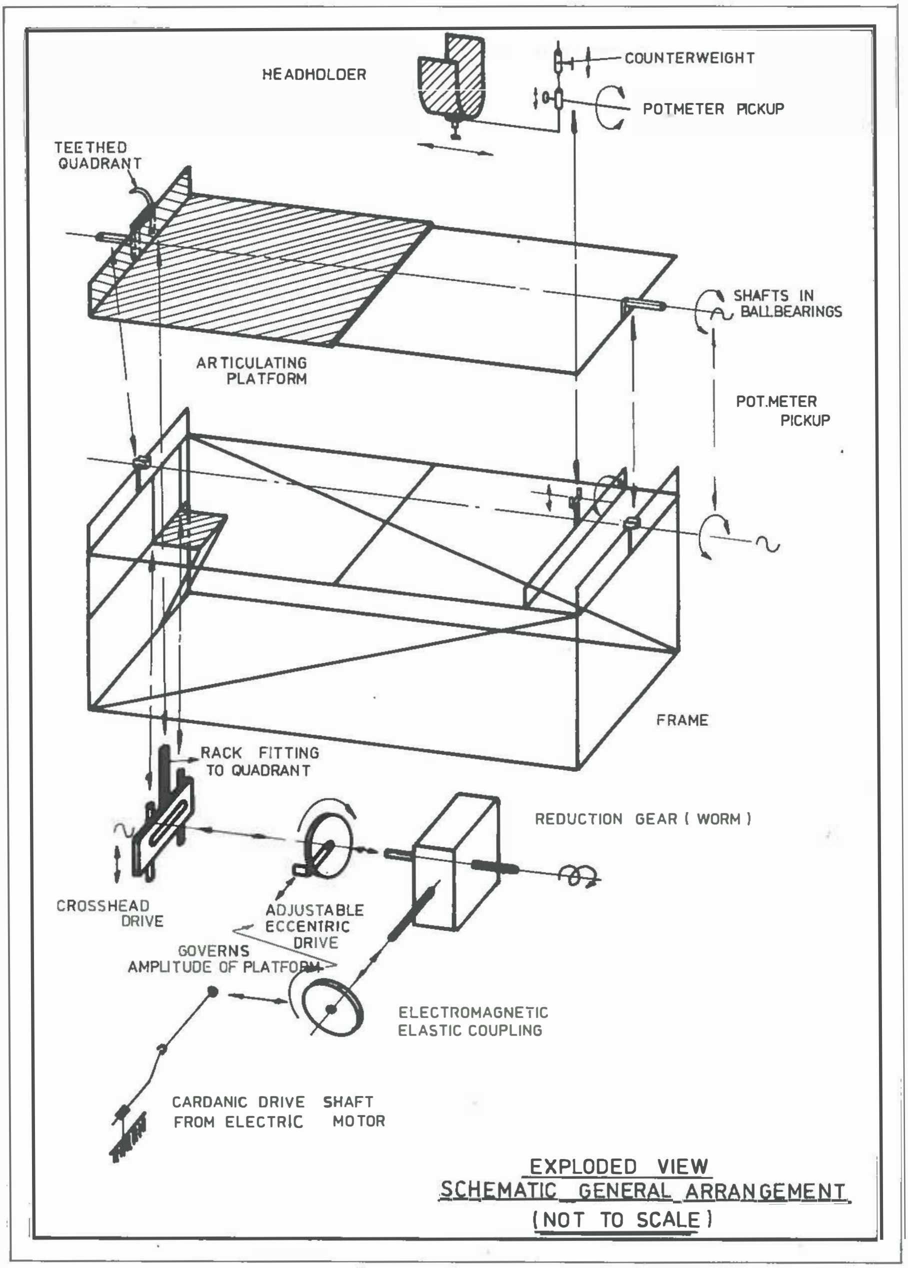


Figure 5.4.-2. Exploded view, schematic general arrangement of the rocking table and of the head-holder.

There exist two supporting surfaces : a smooth surface which was used in the previous experiment and a platform covered with a 3 cm thick soft foam rubber layer. In the latter platform, on both sides of the midline at a distance of 10 cm there are four holes, through these holes strips can be tied to fixate the body symmetrically to the axis of rotation.

The rocking table is driven by an electric motor. This alternating-current motor has a constant number of revolutions of 3000/min. The motor is fixated on a bloc fully separated from the rocking table. By a cardanic drive shaft the 3000 revolutions are transferred into an electronic variators. (Philips type PE 2241/05) By a remote control the output of this variator can be selected; the output is a constant number of revolutions varying between 30 and 2800 per minute; at any desired moment an immediate stop can be selected.
The output of the variator goes by a rigid shaft into a reduction worm. This gear has a constant reduction factor of 50 to 1 and in this gear the direction of the rotation is turned by 90°.

The reduction gear is connected to an adjustable eccentric drive. The degree of the eccentricity determines the amplitude of the sine-shaped movement, since this eccentric drive moves a rack in the vertical direction. The vertical movement is transferred by a teethed rack on an articulating quadrant. By this last quadrant a sinusoidal movement around the rotation axis is produced in the supporting platform.

With the design the movement is really sinusoidal. The amplitude of the sine can be selected in a range between 4° and 20° by adjusting the eccentric.
The frequency can be selected by means of the variator between 0.04 and 1Hz, with an accuracy and constancy within the limit of two percent. In this set-up with the motor fully separated from the rocking table and with the use of the cardanic drive shaft and the electronic variator, the vibrations of the motor and the noise penetrating the acoustic shielding are low and constant. The constancy of these noise factors is guaranteed by the constant number of revolutions of the motor.
Finally the imposed sinusoidal movement can be registrated by a potentiometer placed in the axis of rotation. The movement of the table varies the position and thus the resistance of the potentiometer, this varying resistance results in a varying voltage. After a calibration this voltage is written out on the polygram and on the magnetic tape. The D.C. signal documents the actual position of the rocking table. A signal with a time constant of 3.0 sec is also written out for comparisons with the eye-movements which are registrated in the electrooculograms with a time constant (r = 0.3 sec) (see figures 5.4-4 and 5.4-5).

The head-holder

The requirements for the head-holder can be specified as follows :
The head should rest in a holder symmetrically to the axis of rotation. The distance between the axis of rotation of the head and the part of the head-holder supporting the occiput should be adjustable i.e. the relation between the axis of rotation and the level of support for the head should be adjustable. Papoušek (1961) developed a head-holder to evaluate head-turning as a response in studies on early infant conditioning. He pointed towards some basic principles which to a large extent determine head movements. The baby's head tends to fall to the side if the axis of rotation lies underneath the centre of gravity, e.g. when a newborn lies in supine in his crib the axis of rotation lies in the supporting surface consequently the head rests with the face to the side. If the axis of rotation projects above the centre of gravity the head tends to stay in the mid-

line, the baby must lift his head when turning it to the side. If the axis of rotation passed through the centre of gravity, it is very easy for the baby to turn his head or to keep it in a given position, an attempt is made to approach this last situation in the next series of experiments. (see set y in figure 5.4-3).
The height of the axis of rotation of the head should be adjustable in relation to the axis of rotation of the body, i.e. the axis of the head can be above the axis of the body, (then the head is in flexion), it can be below the axis of the body (then the head is in hyperextention), or it can be coaxial with the axis of the body. This last situation will be used in the next series of experiments. (see set x in figure 5.4-3).
Finally it should be possible to registrate the head-movements.

The design of the head-holder was changed several times to better fulfil these requirements, the head-holder used for the six last newborns can be described as follows (see fig. 5.4-3):
A broad somewhat elastic u-shaped band covered with a 2 cm thick foam layer proved to be best suited for keeping the head centered around the

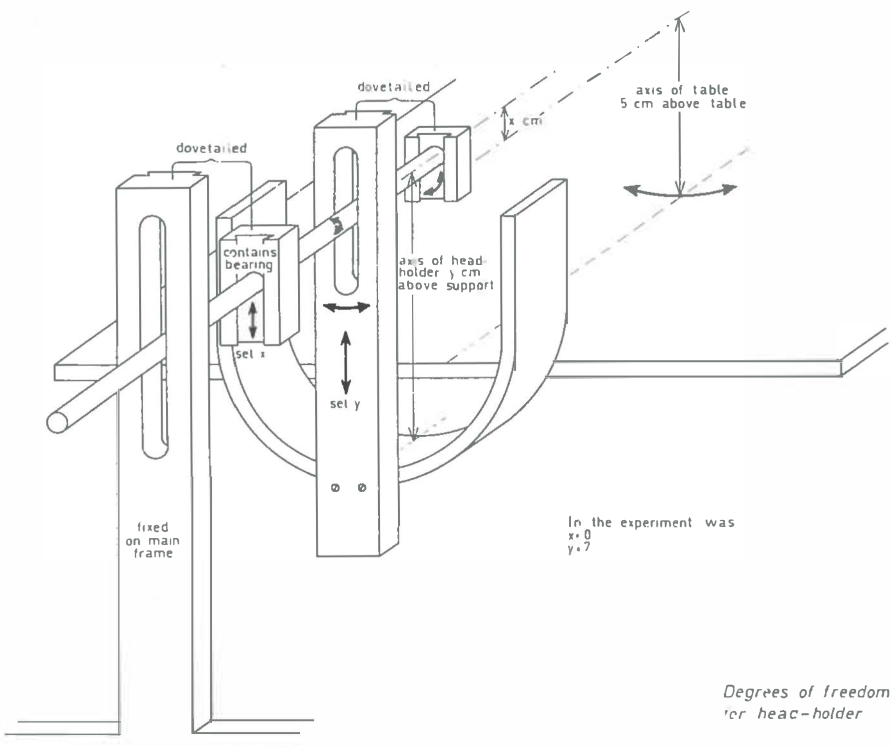


Figure 5.4.-3. Schematic representation of the head-holder, special attention is given to degrees of freedom. Set X is the distance between the axis of rotation of the head-holder and the axis of rotation of the rocking table. Set Y is the distance between the axis of rotation of the head-holder and the support of the head.

longitudinal axis of rotation. The distance between this band and the supporting platform of the body is individually adjustable over a few centimetres along an axis parallel with the longitudinal rotation axis. The relationship between the axis of rotation of the head and that of the body is adjustable since the height of the box, containing the bearings of the rotation axis of the head, can be varied with a dove-tail fitting to a vertical column built on the main frame. I decided to adjust the two axis so that they were in each others prolongation.
The relationship between the axis of rotation of the head and its centre of gravity is determined by the position of another box with a dove-tail fitting inside the head-holder. This design enables one to bring the supporting part of the head-holder at any desired distance from the axis of rotation in a range of 0 to 12 cm i.e. a range equal to the occipito-frontal diameter of the head. This distance will be 7 cm in the following experiments. This position was empirically determined in a pilot study as a situation in which the axis of rotation is close to the centre of gravity but still below it, the head still tends to fall to the side. Because the axis of rotation of the platform is 5 cm above the platform, the level of the occiput is 2 cm below the level of the body in the chosen experimental situation.
By this last adjustment, however, a different amount of weight of the head-holder is lying above and below the axis of rotation, therefore a counterbalance weight adjustable along a vertical axis is available. Once the axis of rotation is determined, e.g. at 7 cm, then the head-holder (without a head) is counterbalanced in such a way that the position of the head-holder is stable in any given position between 0 and 180 degrees. Finally, a second potentiometer has been built in the axis of rotation of the head-holder to registrate the head movements. The output from this potentiometer is calibrated and written out on the polygram and on the magnetic tape. The D.C. registration tells us the actual position of the head, the RC (r = 0.3 sec.) registration, allows us a comparison with the electro-oculography (see figure 5.4-4 and 5.4-5).

Already now it should be stated very clearly that with this head-holder only those head movements can be studied, that occur along a longitudinal axis. Small head movements along a transversal biparietal axis and along a vertical fronto-occipital axis cannot be registrated, although (to a small extent) they do occur inside the head-holder. Finally, a small degree of inclination forwards and backwards between the frame supporting the head-holder and the main frame is tolerated to improve the individual adjustment of each baby in the system.

5.4.2.2. *Subjects and methods*

Ten newborns (group H and H' in table 2.1), with birth weights between the 25th and 90th percentiles, aged 4 to 8 days, were studied. In a pilot group of four babies, during at least one full behavioural-state cycle, the spontaneous head movements in the head-holder were studied; the rest of the observation-time, lasting 2 to 6 hours, was used in these 4 newborns to test the rocking procedure.
In a final group of six newborns the total observation time, lasting between 3 and 4 hours, was devoted studying the effects of longitudinal rocking. The body was rocked with a constant frequency of 0.3 Hz and an amplitude of 15 degrees; the head-following movements and the spontaneous head movements were studied.
Simultaneously with the observations a polygraphic recording and a series of photos were made. Besides the standard physiological variables (respiration, heart-rate, electro-encephalography, electro-oculography and

electromyography) a D.C. recording of the head-position, and RC (r=0.3 sec) recordings of both head and body positions were made. An attempt was made to record the activity of the sternocleidomastoid muscles with surface electromyography. (see fig. 5.4-4)

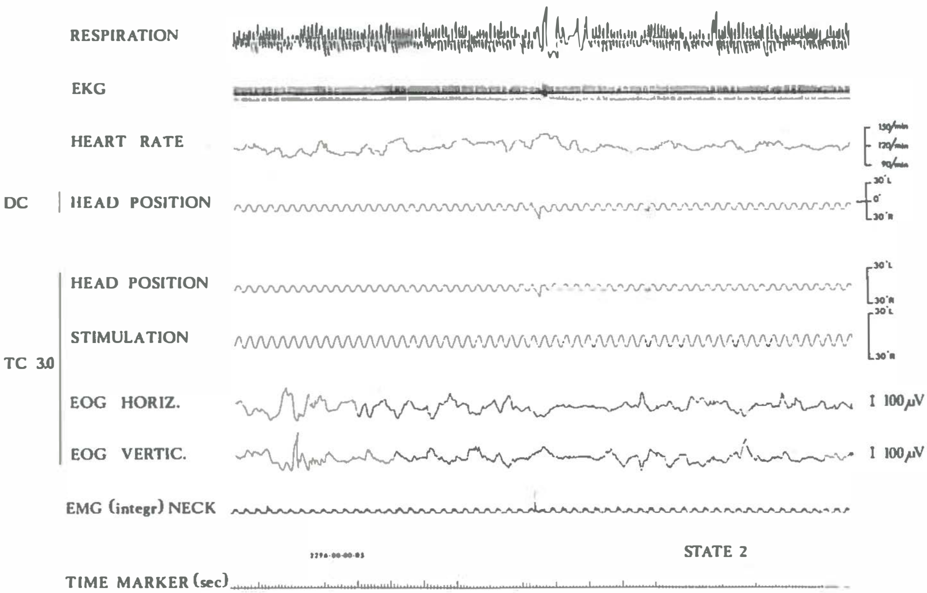


Figure 5.4.-4. Sample of a playback of a polygraphic recording in a newborn (age 5 days) during longitudinal rocking. The movement is imposed by the rocking table (see stimulation), the head-following movements are studied.

5.4.2.3. *Results*

Spontaneous head movements

Spontaneous head movements were studied in the following condition : the body up to the shoulders was resting on the supporting platform of the rocking table; two strips, one at the level of the shoulders and one at the level of the hips, kept the baby centered. The head was resting in the head-holder, the axis of rotation of the head and the body were in each other's prolongation.

The active awake newborn made very strong and brisk head movements in the head-holder, the head turned from one side to the other. These head movements were so strong that they elicited intense total body movements. Since the babies did not look comfortable in that situation, they were pacified with a nipple. As soon as a newborn received a nipple, the total picture changed; the face centers around the midline, in most newborns a few degrees to the right side. With the nipple the baby looked very comfortable in the head-holder; with his eyes open, he glanced around.

The head stayed in the same position for several minutes, the arms were flexed, the hands stayed close to the face and the legs were extended or semi-extended.
After the onset of sleep, the face turned to the side; if the head turned quickly a reaction was observed, consisting of a total body movement including a head-turn back to the center. If the head-turn was slow, then the head stopped at a position varying between a few degrees up to 90° degrees to the side.
Asleep, in state 2, the head did not remain for a long time in a given position since there were at least three different types of spontaneous head movements. At the occasion of gross-body movements there was always a change in the head position and it was hard to predict before a movement at which angle the position of the head would be after the movement. Isolated head movements did also occur, the head suddenly glided further to the one or the other side. Finally small very brisk and short lasting changes in the position of the head took place; these head movements reminded the observers of twitches in the extremities or of rapid eye movements.
After such an epoch with a constantly changing head-position, i.e. state 2, a period with a very stable head-position followed, i.e. state 1. During state 1, it was amazing to see how the position of the head remained on the same co-ordinates for a period of twenty to twenty-five minutes (see figure 5.4-5). Even at the occasion of a startle or a jerk in

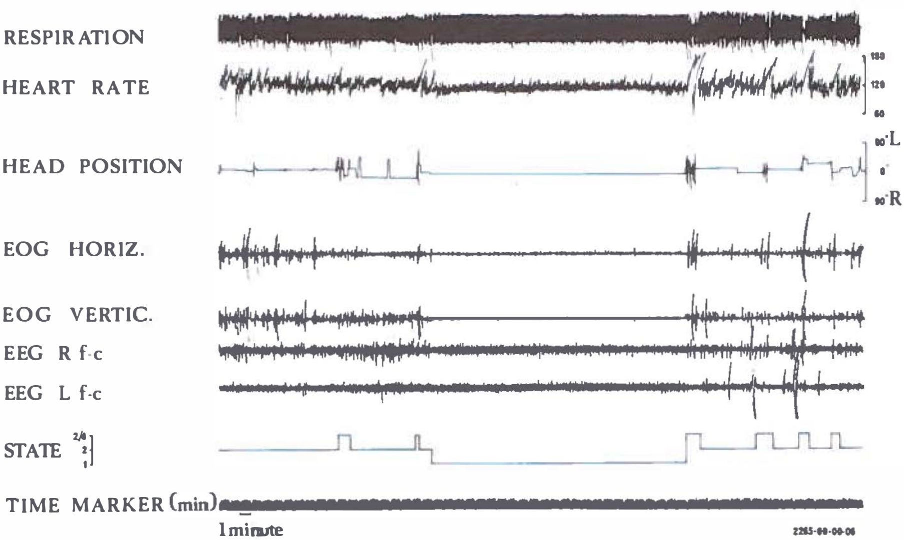


Figure 5.4.-5. Sample of a play-back of a polygraphic recording of a newborn (age 6 days) resting on the rocking table with his head resting in the head-holder. There is no imposed movement, spontaneous head movements are recorded. Note the abscence of head movements and the stability of the head position in state 1 (2/4 in this figure means gross-body movement in state 2).

state 1 the stable position of the head remained almost the same; the head turned sometimes a few degrees more to the centre or more to the side. In the head-holder at the transition from state 2 into state 1 frequently a gross-body movement with a few seconds of frowning and fussing was observed; it even occurred that the newborn awoke or that he was given a nipple since otherwise he would wake up.
Newborns who fell asleep while sucking on a nipple showed a more stable head posture in state 2. Later, asleep, at the same moment when their head glided away they also lost their nipple.

From these observations of non-rocked newborns a number of conclusions can be drawn :
Spontaneous head movements, and thus changes in the position of the head, are obviously state dependent phenomena.
Non-nutritive sucking on a nipple improves the stability of the head posture both in awake and in sleeping newborns.

Head-following movements

Head-following movements during sinusoidal rocking of the body were studied in the various behavioural states. The sine had a frequency of 0.3Hz and an amplitude of 15°.
From the pilot studies both these parameters of the sine seemed suitable for an experiment in which body and head were not resting on the same platform. The body, up to the shoulders, was placed upon the supporting platform of the rocking table, the body was extra stabilized by two foam rolls, placed on each side of the body, inside the fixating strips. The head-holder was free from the rocking platform; the occiput was resting in the head-holder at a level that lies two centimetres underneath the level of the body; by this setting of the head-holder the axis of rotation of both head and body were approximately brought in each other's pronlongation. The support of the occiput is seven centimeters below the axis of rotation of the head, by this setting the axis of rotation projects certainly not underneath the centre of gravity of the head and perhaps not too much above it.

Behavioural observations and visual analysis of the polygrams

In the awake babies during rocking it was difficult to control the experiment without giving a nipple . With the nipple, however, during rocking movements the newborns fell immediately asleep; none of the six newborns stayed longer awake than 3 to 5 minutes during rocking; this was a suggestive but not a conclusive finding since there was no intraindividual control for this parameter available in these observations lasting only three to four hours.
Falling asleep, as in the non-rocked newborns, the head glided to the side, this means that the co-ordinates, around which the following movements took place, changed at the onset of sleep. Further in state 2 these co-ordinates continued to change at irregular intervals due to the gross-body movements. Even in those minutes in state 2, in which no gross-body movements occurred, the middle position around which the head was rocked was not always the same, there were isolated rather slow head-turns and also very brisk and sudden changes in the head position, into which the rocking movements were superimposed.
The amplitude of the head-following movements was in all states smaller than the amplitude of the body movements. This amplitude of the head movements was, however, to a large extent determined by the position of the head, e.g. head-following with the face about in the midline resulted in a movement of 5 degrees to the right and 5 degrees to the left when

the amplitude of the body movement was 7.5 degrees; an identical body movement, with the face at 70 degrees to the right, resulted in asymmetric head-following 2 degrees to the right and 7 degrees to the left. From this example it can be seen that not only the peak - to - peak amplitude of the head movement was influenced by the position of the head but also the symmetry and shape of the head-movement was influenced by the actual position of the head.

In contrast, in state 1 the co-ordinates for the head-following movements were amazingly stable. Just before or at a startle or a sigh the head-position could change but after this episodic event it returned to completely or almost the same co-ordinates.
The transitions from state 2 to state 1 were inter- and intra-individually different; sometimes over a period of ten to twenty head-following movements, i.e. 30 to 60 seconds, there was a slow change in the head-position from the side to the centre, at other occasions there was a gross-body movement accompanied by a head movement and after such a repositioning the body and head posture remained stable for the next twenty to thirty minutes.
The transitions from state 1 to state 2 could at other occasions consist of a slow drift to the side of the head-position, but more frequently a gross-body movement (with sometimes vocalization or with a few seconds with frowning and fussing) frequently marked the end of a state 1.
The head of sleeping newborns, who had a nipple and who were non-nutritive sucking, followed the body movements more accurately, the head-position remained more stable over time and the amplitude of the head movements was the largest that we ever observed; it ranged from 10 degrees to 12 degrees with a body movement with an amplitude of 15 degrees.

Before some quantitative aspects of the head-following movements will be discussed, some comments on the changes in body posture during the rocking experiments are indicated here. Although an attempt was made to fix the body, differences in the manner in which the body followed the moving platform were seen in the various behavioural states. This was most easily observed by looking at the extremities.
The awake newborn during non-nutritive sucking and the sleeping baby in state 1 moved as a whole ("en bloc"). There was no phase lag visible between the movements of the platform and the body with the semiflexed arms and the usually semiflexed legs.
In state 2, however, the table moved already, for example, to the right side before the body and certainly before arms and legs started to follow; at the moment of a change in direction it took again a while before the arms and legs started moving into the other direction; all observers agreed on describing this phenomenon as a phase lag between the extremities and the table. It was not so easy to measure whether there was also a phase lag between the body and the table.

Quantitative analysis of the head-following movements

From these behavioural and qualitative visual analyses the main conclusion is the enormous inter- and intra-individual variation in the relative head-to-body positions, the intraindividual variations are state dependent and in state 2 this variation is determined to a large extent by the gross-body movements.
This conclusion has not only methodological implications for the quantitative analysis of the data but it means that the inputs coming from the vestibular organ and from the receptors in the cervical joints, in the neck muscles and in the neck joints, differ each time when the position of the head changes, even if the rocking movement imposed to the body

remains absolutely constant over time.
Each analysis that attempts to define aspects of head-following over long epochs tells us mainly that there are differences in the quality and the quantity of gross-body movements in these epochs; e.g. a comparison in state 1 and state 2 of the mean amplitude of head-following movements and of its variation, or an analysis of the phase lag between the head and the body and its variation are indirect ways of describing the absence of movements in state 1 and the presence of movements in state 2.

This point can be illustrated with a few examples of the employed superposition analysis technique (see figures 5.4-6,-7 and -8). With the aid of an oscilloscope a Dawson superposition analysis was carried out of the final six rocking experiments by off-line analysis from the position-signals , stored on magnetic tape, of the head-holder and the rocking table. The analysis proceeded as follows : the signal from the potentiometer of the rocking table was used as the external trigger for the oscilloscope, actually the downwards directed zero-crossing of this signal was the

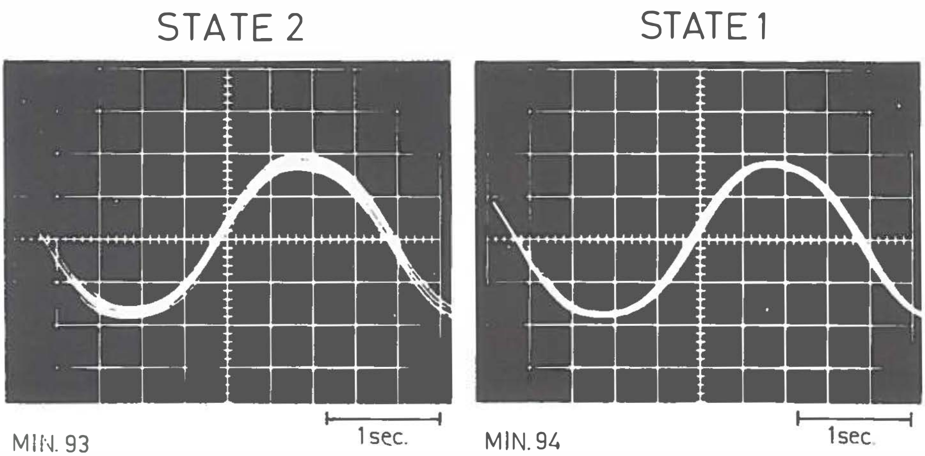


Figure 5.4.-6. Twenty super-imposed sweeps of head-following movements, in a quiet minute of state 2 and in state 1. The trigger for the oscilloscope is the downwards directed zero-crossing of the signal from the potentiometer of the rocking table. Note that the broadness of the band (i.e. an estimate for the reproducibility of the individual head movements) is broader in the last minute of state 2 than in the first minute of state 1.

trigger. The signal from the potentiometer of the head-holder was written out, on the oscilloscope, twenty sweeps were super-imposed, each sweep lasted about 3 seconds, the analysis time was thus about one minute. A document of the oscilloscope screen was obtained by a photographic exposure of one minute.
In figures 5.4-6,-7,-8 there are 9 samples, each representing 1 minute and 12 seconds, since a single oscilloscope sweep was 3.6 seconds. In figure 5.4-6 and 5.4-7 the samples at the top are derived from state 2, the

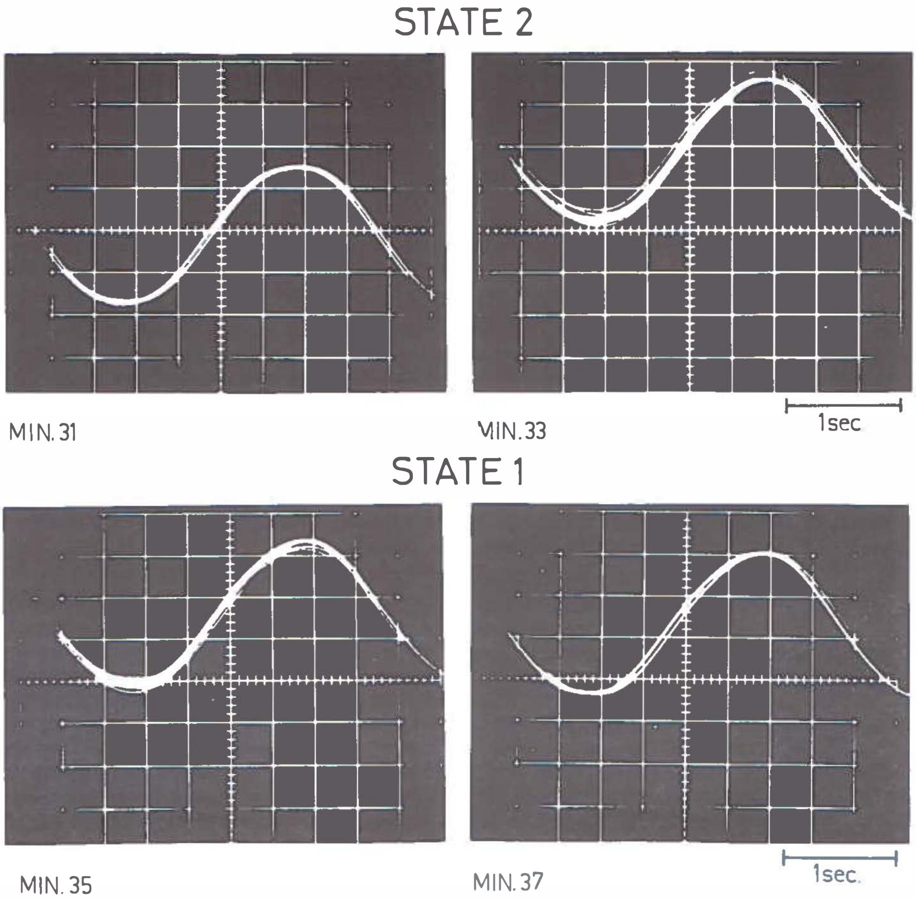


Figure 5.4.-7. Four samples of each twenty superimposed sweeps of head-following movements, two in state 2 and two in state 1. Note that beside the broadness of the band, also the level (i.e. the co-ordinates around which the head movements take place) is unstable in state 2 and is stable in state 1.

samples at the bottom are derived from state 1. Figure 5.4-8 illustrates a transition from state 1 into state 2. From these examples it can be seen first, that in state 2 the level around which the rocking took place varied from minute to minute; secondly that the broadness of the band, i.e., the variation in the reproducibility of the individual head movements was larger in state 2 than in state 1. Fig. 5.4-8 illustrates the loss of stability in a transition from state 1 into state 2.

Finally, to answer the question whether differences existed between the head-following in epochs in state 2 without movements and in state 1, the coherence between the two position-signals was computed in carefully selected epochs.

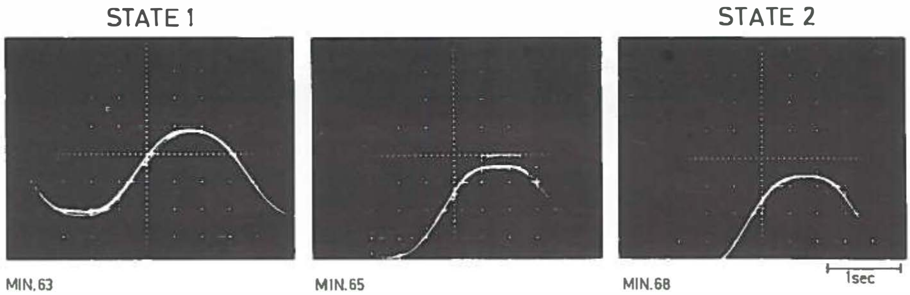


Figure 5.4.-8. Three samples of each twenty superimposed sweeps of head-following movements at a transition from a state 1 into a state 2. These samples illustrate that the head glides to the side, thus the co-ordinates change in this transitions from state 1 into state 2,

The epochs to be analysed were selected on the following criteria : there were no gross-body movements, neither during the epoch for analysis nor one minute before or after this epoch; the movement during the epoch for analysis was sinusoidal and no obvious asymmetry in the amplitude of the sine could be seen on the write-out. It was not difficult to find such epochs in state 1; to find epochs in state 2 that could be compared with epochs in state 1, however, was difficult in this material due to the movements in state 2.
The coherence function is a measure for the correspondence of two signals in the frequency domain. The off-line analysis started with an analogue-to-digital conversion of the two signals, stored on magnetic tape, with the aid of a general purpose computer (PDP-15).
With a fast Fourier analysis the autospectra of the two position-signals and their cross-spectrum were computed, and from these spectra the coherence function was derived :

$$\text{coherence} = \frac{|\text{crossspectrum}|^2 \ \text{(head-holder and rocking table)}}{\text{autospectrum (head-holder)} \times \text{autospectrum (rocking table)}}$$

(see e.g. Jenkins and Watts, p. 362, 1968.)
The output of these computations appeared graphically on the display screen of the computer and numerically on the tele-type. For further details of these computer analyses the reader is referred to Vos (1975).
In state 1, in all six babies, the coherence was most of the time between 0.98 and 1. In state 2, the coherence was most frequently lower than 1, ranging from 0.80 to 0.98. In two babies comparisons of epochs in state 2, in state 1 and during awake non-nutritive sucking, fulfilling the above mentioned criteria, were possible, the results are listed in table 5.4-2.
From these few examples it can be concluded that head-following in state 1 is more precise than it is in quiet parts of state 2. This means that there are differences in the body-head transfer in these two states that are not fully explained by the presence or the absence of movements. It is interesting to see that also during non-nutritive sucking in the awake newborn the coherence function is 1; in this behavioural condition an actively controlled head posture is obvious.

TABLE 5.4-2

Coherence function between head movements and body movements

	State 2	State 1	Awake non nutritive sucking
Baby 2353			
7 min.	< 1	1	-
3 min.	< 1	1	1
Baby 2354			
6 min.	< 1	1	-
3 min.	< 1	1	1

5.4.2.4. *Discussion and comments on the experiments with rocking about a longitudinal axis*

Head-following movements in state 1 are thus more precise than head-following movements in the quiet epochs of state 2. They are similar to head-following movements in the awake non-nutritive sucking baby; this last finding is a strong argument to consider the precise following as an actively controlled phenomenon. Another argument for the presence of an active control in state 1 is the high stability in the co-ordinates of the head-position, both in the experimental condition without rocking and in the experiments with rocking. A plausible explanation could be an increased sensitivity of the muscle spindles to stretch, due to an increased gamma drive during state 1.
A second finding is the enormous intra-individual variation in the head-body relationship in state 2 in both experimental conditions. This variation is partly explained by the interference of gross-body movements. There exist, however, also small sudden and brisk head movements in state 2; in their appearance these head movements show similarities with the REMs and the twitches in the extremities observed during state 2. About the origins of these phenomena we can only speculate; irregular firing out of the vestibular nuclei along the vestibulo-spinal tract on the alpha motoneurones,is one of the possibilities to think of. Finally in periods without any visible head or body movements, the head following is still less precise in state 2; this may be explained by a lower sensitivity of the muscle spindles to stretch, due to a lower gamma drive in state 2. (see General Discussion, paragraph 6.2).

During these experiments consistent doll's eye phenomena were neither observed nor recorded in the electro-oculograms. They were not found in any of the used quantitative analyses, such as the superposition technique, the frequency analysis and a cross-correlation analysis. A first explanation for this absence would be that the stimulus intensity remains below the treshold required for eliciting vestibulo-ocular responses. With body rocking of 15 degrees and 0.3Hz, the head-movements are about 10 degrees at 0.3Hz, the actual stimulus for the vestibula is thus an acceleration of 3 degrees per sec^2. Von Bernuth and Prechtl (1969) with stimuli of two or three times this magnitude found good and consistent responses.

These stimulus intensities are too high for the present experiments, in which the baby's head is restricted in a separate head-holder.
There is, however, another explanation; in the present experiment the inputs from the neck-proprioception and from the vestibula have the same direction, while in the experiment of Von Bernuth and Prechtl, in which the head was fixated on the rocking platform, inconsistencies between the inputs from both sensory modalities might have been present.

Up to here no data on the electromyography have been reported.
The recordings of the sternocleidomastoid muscles showed very large inter- and intraindividual inconsistencies. The fixation of the electrodes on the skin overlying the muscles allowed too many displacements during positional changes, furthermore we consider the signal-to-noise ratio too bad; therefore changes observed in the electromyograms might be as much related to changes in the electrode-to-muscle relationship as to the actual firing of the muscles.
In one baby, during the pilot study (see fig. 5.4-4, baby 2296) a good sternocleidomastoid muscle recording was obtained throughout the whole observation. This baby had a cephalic-brow presentation in utero, his neurological examination was normal but he showed a slight tendency to overextend his head. This baby showed consistent firing in his sternocleidomastoid muscles in all behavioural states; the activity was strongest in the awake states, it was weaker but consistent in state 1, and it was very weak but still consistently present in state 2. With the EMG technique used in this and in previous experiments consistent firing in state 2 has never been seen. The finding in this baby may be due to a different setting of the sensitivity of the muscle-receptors to stretch, since the neck muscles of this newborn were differently active in utero, during the descent and the delivery of his head in brow presentation. Exactly these differences in motor output in relation to actual and previous positions and positional changes, are the questions we would like to study; we need however, to improve our surface electromyography before this aim can be achieved.

Comparing the present experimental procedure with the experimental procedures in which the total body including the head is placed on the moving platform either for longitudinal or for transverse rocking, it is obvious that the present experiment is more difficult. It is more difficult to keep the experiment going smoothly and it is difficult to compare the results between babies and between the various states in one baby; these difficulties are mainly related to the enormous state dependent variation in the head-body relationship. In terms of mechanisms this means, for instance, that the inputs from the receptors are constantly changing during the present experiment. On the other hand, what is called difficulties are actually inter- and intraindividual differences in postural behaviour and postural adjustments. They are an interesting finding and they should be taken into account in the planning of further experiments and in the interpretation of the results of previous experiments.
In future experiments I would like to place the whole baby on the platform, acceleration-tranducers would be taped on the head and on the body to record the manner in which the head and the body react to imposed positional changes. During the present experiments an accelerometer of only a few grams was tested. This transducer was developed in the Technical University of Twente to study tremors in adults; the signal to noise ratio, however, was too poor at the low frequencies used during our rocking experiments. Kresse and Rettenmaier (1973) developed a small potentiometer that could be fixed to the body, to study body movements during sleep, but the resolution of this transducer was too small (7 de-

grees) and this accuracy required already that the transducer had a minimal weight of 40 grams. Both specifications make this position-recorder inadequate for the present study. It is obvious that more energy must be invested in developing better techniques.

During further experiments better electromyographic recordings are needed as badly, since besides the actual positions, also the actual motor output that is required to maintain a posture or to resist to a positional change should be measured. Therefore in the last series of experiments of the present study an attempt is made to improve the surface electromyography in such a way that differences in the motor-output can be measured in those muscles, which are presumed to be active in postural control.

5.5. POSTURAL BEHAVIOURAL AND MUSCLE ACTIVITY IN NEWBORN INFANTS

In this section a series of examples will be given to illustrate the fact that changes in postural behaviour can be directly correlated with changes in the muscle activities as recorded by surface electromyography; the examples will bring first evidence that the observed active postures during our previous observations on spontaneous postural behaviour in various orientations and during imposed positional changes are the result of neuromuscular activities and not merely the result of visco-elastic properties.

As stated previously, consistently good recordings of low level tonic muscle activities were not possible with the surface electromyographic technique used up to this moment in the present study and in other studies inside and outside our research group. Relatively good recordings of tonic muscle activities were only possible in the chin-muscle EMGs. For that reason, since Roffwarg et al. (1964) demonstrated that in newborns there is a higher percentage of time with tonic activity in the chin EMG in non-REM sleep, the chin EMG has been used as one of the physiological parameters in infant sleep research (see e.g. Anders et al., 1971). Roffwarg et al. (1966) gave a qualitative description of changes in the chin muscle activity in relation to the behavioural states : they describe a diminution of the muscle activity at the onset of sleep, an increase during the transition from REM sleep into non-REM sleep and a gradual diminution preceding a REM period.
In the present study the interest is not restricted to the chin-muscle group, but also to the activity of different muscles involved in postural control in the various behavioural states, with special attention for the so important neck-muscle group.

5.5.1. Subjects and methods

Fourteen newborns (group I and I' in table 2.1), with birth weights between the 25th and the 90th percentiles, aged 4 to 5 days, were studied. The recordings lasted between two and six hours. Ten recordings were fully devoted to the improvement of the methods to record tonic muscle activities. These ten newborns were studied during feeding and during spontaneous behaviour in various positions, these positions were selected in such a manner that certain muscle groups were brought under an increased stretch. The last four newborns were studied during sucking and while placed in the side position; during these recordings the technical problems had so far been solved that a qualitative description of tonic activities especially in the neck muscles was possible.
Before discussing in some detail the improvement of the electromyographic technique, a few remarks on the other physiological signals and the visual documentation are indicated. Besides the EMGs, also respiration, heart rate and eye movements were recorded. To document the postural behaviour photographs were made in six newborns, in the last five newborns the time-lapse photography was used (for details see paragraph 3.4-3). In these series of experiments, focussing on both technical and physiological problems, always three observers were present. One observer dictated comments on a dictaphone during the whole experiment. The write-out of these comments proved to be useful as a record for unexpected behavioural, physiological and technical events.

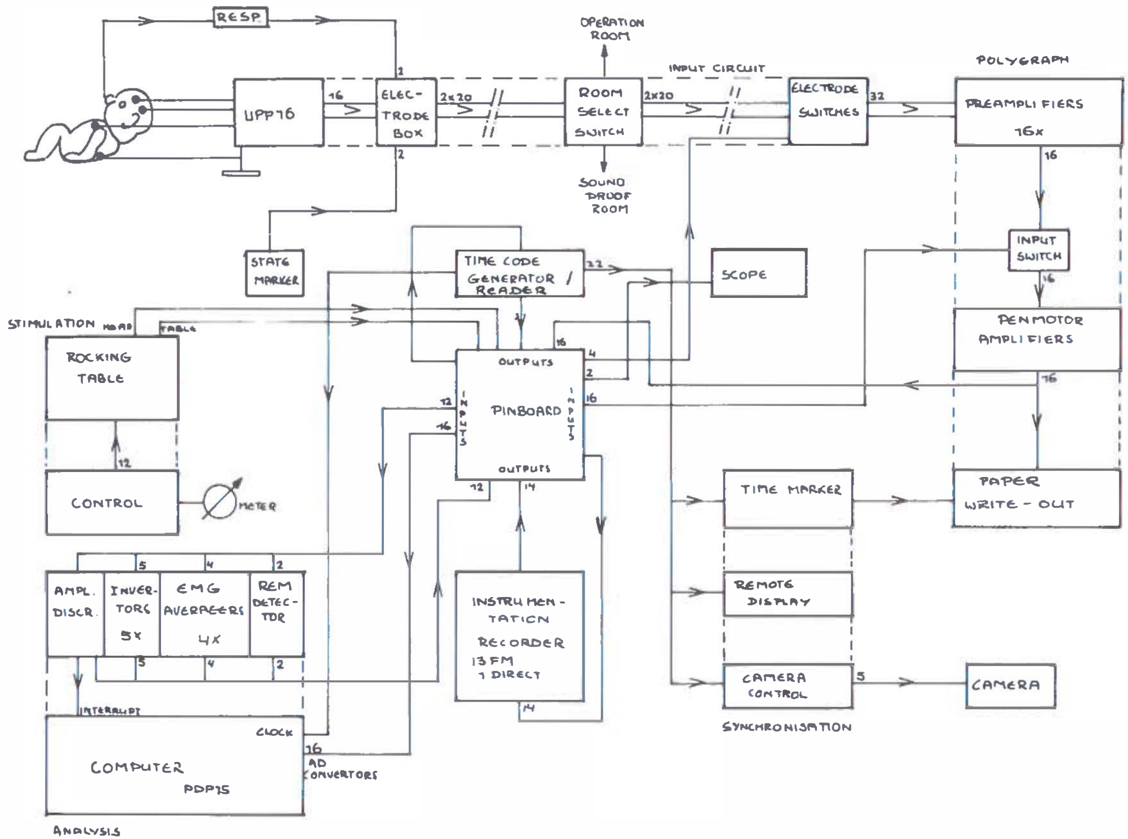


Figure 5.5.-1. The instrumentation circuit as used in this section.

5.5.2. Technical note : the surface electromyography

Before starting a discussion on problems and improvements, a short description of the surface electromyographic technique as it was used in previous studies in our department and in previous sections of the present study is indicated here.
The skin electrodes, two silver rods, 2.4 mm in diameter, are mounted at a distance of 1 cm in a perspex plate, 13 x 30 x 3mm. These electrodes are covered with commercial electrode paste and placed over the appropriate muscle after careful skin preparation. The perpex plate is firmly strapped to the skin with hospital tape. With two flexible cables the signal is brought, over a distance of 50 cm, into the electrode-box, from here onwards the signals, together with other signals, are transported through a multichannel cable over a distance of about 15 metres to an Offner-Beckmann set of preamplifiers, and penmotoramplifiers. Thus only after the 15,5 metres of transport the signal is amplified and filtered. The amplifications result in a write-out of 250 µV/cm; a time constant of 0.03 seconds is used. The high frequency filters of the Offner-Beckmann are in the off-position to record as much as possible of the EMG activity. Those EMG signals are also written on analogue tape, and on-line or off-line EMG integrations can be carried out with the Offner-EMG Integrator type 9852.
This EMG technique was very satisfying in a whole series of studies in which the presence or absence of responses to stimuli of various sensory modalities were studied (for a review see Prechtl, 1974). The same approach was used in the present study for the description of the amount and the distribution of gross-body movements and startles in the various positions.
During the present study especially in the section on postural reactions due to imposed positional changes the following problems with this technique could be identified :
The fixation of the electrodes to the skin is not stable enough during long recordings and especially not during imposed positional changes (see the neck muscles during the rocking experiments), the impedance between the skin and the electrode is thus not constant throughout the experiment.
Related to this problem is the fact that the electrode paste, placed on top of the silver rods can move, the electrode can make a direct contact with the skin and even a direct short circuit in the sensor is possible by a bridge of paste between the two silver rods.
Beside these hazards at the most vulnerable place in the signal transport, namely the skin-electrode transition, the other constant threat of picking up all types of parasites, especially the 50Hz hum of the mains, is the great length of the signal transport cable.

Step by step this system has been improved by L. Van Eykern, the electronic engineer of our department, in collaboration with several members of the Central Electronic Workshop of the University of Groningen and of our department. These improvements were first tested on ourselves but afterwards testing in newborns proved to be necessary, since the differences between adult and newborn muscle and skin parameters appeared to be large. In the last four babies studied in the present group the following system could be used (small changes have been added after the present study, they are described in brackets).
The electrodes are now two sintered Ag/AgCl/Pl-pellets measuring 4 mm in diameter [Annex Research]. Each pellet is placed in a separate perspex block constructed in such a manner that a thin layer of electrode paste is always present between the skin and the electrode pellet, a direct skin-

electrode contact is no more possible; a small side-hole allows an easy injection of the electrode paste between the skin and the pellet. The perspex is taped with a tape which is adhesive on both sides; one side is taped to the perspex with a central hole for the electrodepaste-to-skin contact, the other side is taped to the skin; movements between the skin and the electrode are now excluded. The electrodes are placed in such a way that the centres of the two pellets are 14 mm apart. The electrodes are placed on top of the bellies of the biceps brachii and the quadriceps femoris muscles; these muscles are easy to identify in the newborn. For the chin muscles, i.e. mainly the mentalis muscle and the orbicularis ori muscle the electrodes are placed underneath the mouth frontally on the chin. The electrodes for the sternocleidomastoid muscles are placed on the muscle belly in such a manner that the center of interpellet distance is at 2 cm from the mastoid process; when the awake baby resists to a passive turning of the face to the opposite side, the muscle belly becomes clearly visible. (At present to keep the interelectrode distance more constant, the two pellets are mounted in one perspex block, but in such a way that a perspex bridge between the two electrode-paste-holes excludes direct contacts between the two electrodes, the whole sensor measures now 10 x 24 x 4 mm).
Highly flexible shielded cables are adapted to the electrodes by means of a miniplug, which allows spontaneous disconnection in case of strong tensions. These cables are also about 50 cm in length, they transport the signal to the Universal Physiological Preamplifier [U.P.P. - 16] which is the further major step in the improvements of the system. This unit is mounted above the baby-bed in the immediate vicinity of the electrodes (see flow diagram in fig. 5.5-1). This unit has a separate power supply, namely a 24 volt battery. The gain of the D.C. amplifier is 50, and an impedance transformation from 100 M Ohm input to a 2 Ohm output takes place. The amplifier has an excellent common mode rejection factor, i.e. components common to the signals [like 50Hz mains interference] are almost completely rejected. By this unit physiological signals with a low voltage and a high impedance are transformed in signals with a higher voltage and a low impedance. These last signals are suitable for transmission; the risk of distortion, cross talk and line interference during the transport to the Offner-Beckmann Polygraph is reduced enormously. In the amplifiers of the Offner-Beckmann the signal is further amplified so that the write-out gain is 250 μ V/cm, the time constant remains 0.03 seconds.

On-line or off-line these EMG signals can now be averaged instead of integrated. For this purpose the EMGs are first filtered through a band-pass filter between 50 and 150 HZ, this band-pass filtering was empirically found to be an appropriate filtering for the chopper noise of the Offner-Beckmann amplifiers (at present in our department a separate bank of preamplifiers without choppers has been built; it should be mentioned that also in the new Offner-Beckmann Polygraph the choppers have been omitted). The filtered EMG is then full-wave rectified and averaged in a third order filter (Garland 1972) with a rectangular time-window of width, T=200ms. These averaged signals are logarithmically amplified and written out on the polygram and they can again be stored on the analogue tape. An analysis of the improved surface EMGs and their averaged correlates of our last four recordings is possible. A further quantitative analysis is the topic of two further studies (O'Brien et al., 1975, Schloon et al., 1976).

5.5.3. Results and comments

5.5.3.1. *Postural behaviour and muscle activity during sucking*

The most promising behavioural situation to be studied is the postural behaviour during sucking, since this posture looks very active, very mature and well co-ordinated. The changes in posture at the onset of sucking have been discussed in paragraph 4.3. The drawings, displayed here, are made from the time-lapse photographies of the posture before and at the onset of non-nutritive sucking on a nipple in a 5-day old newborn in the supine position. In fig. 5.5-2 the corresponding polygram with the surface electromyograms and their averaged signals is given. Before the onset of sucking the face is to the left, there is a strong tonic activity in the right sternocleidomastoid muscle (R. Neck in fig. 5.5-2). When the nipple is inserted in the mouth the face turns to the midline, a phasic activity in both sternocleidomastoid muscles takes place, and is followed by more symmetrical tonic activity in the two neck muscles. During sucking there is a sustained increase in the tonic activity of the chin muscle, of the neck muscles and of the biceps muscle. This last muscle, however, was already rather active before the sucking started. Phasic bursts are superimposed on this tonic activity in the chin and the neck muscles simultaneously with the sucking movements and the accompanying head movements.

This behavioural physiological correlate was consistently observed in this material, the increase in tonic activity in the neck and biceps muscles was always present, the changes in the quadriceps muscles were more variable, they were influenced by other factors such as the orientation of the body and the degree of flexion in the hips. These results have been previously published by Casaer et al. (1973) and they are confirmed in a new group of newborns using the same electromyographic technique by Schloon et al. (1976).

5.5.3.2. *Postural behaviour and muscle activity in the awake newborn*

Active awake and crying newborns show strong flexion and extension movements. Mortier and Prechtl (1971) demonstrated that they are mostly the result of co-contractions in antagonistic muscle groups. In the present study with the new EMG technique it could be demonstrated that in the awake newborn the movements are phasic increases in the muscle activity which are superimposed on varying amounts of a continuously ongoing tonic activity. In fig. 5.5-3 to 5.5-6 a series of examples of EMG correlates of various types of movements are illustrated. In fig. 5.5-3 the activity of the left sternocleidomastoid muscle is illustrated, the baby is in

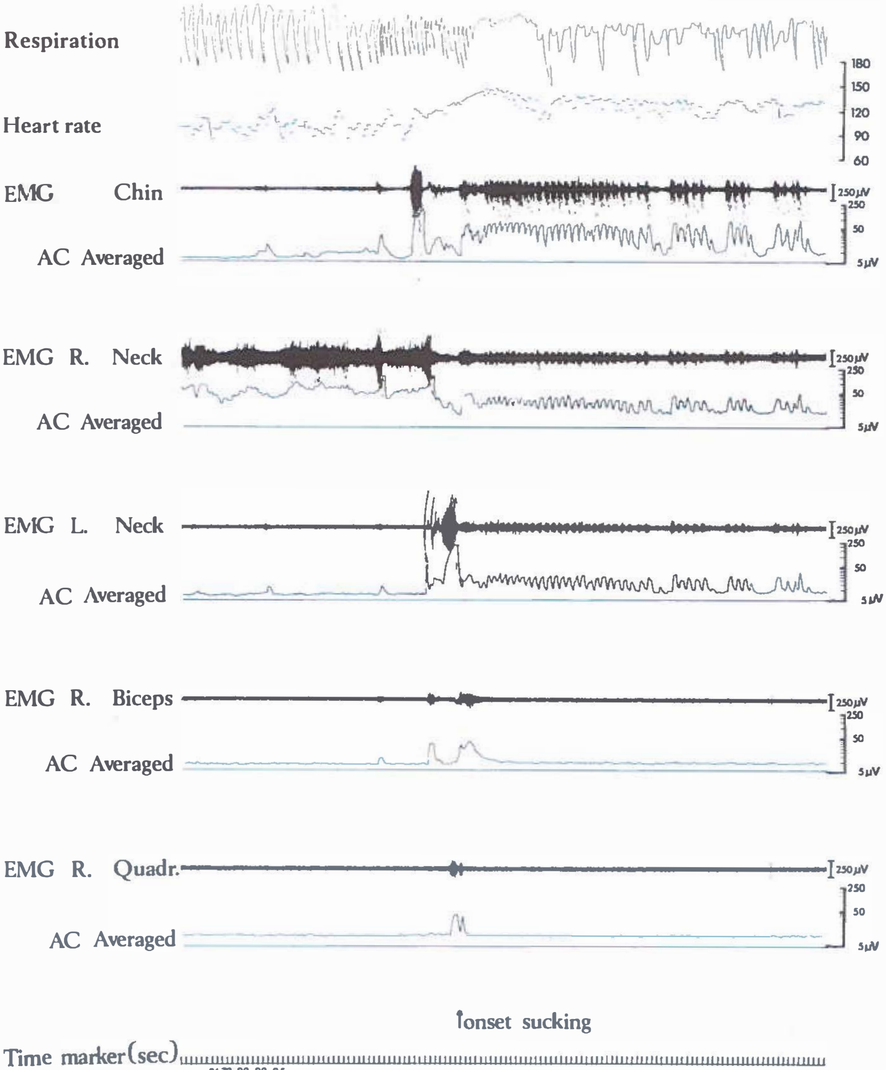


Figure 5.5.-2. Sample of a polygraphic recording of a five day old active awake newborn in supine position at the onset of sucking. Before the sucking the baby faced towards the left (see the high tonic activity in the right Sternocleidomastoideus). At the onset of sucking the head becomes actively centered, the tonic activity in the sternocleidomastoid muscles becomes more symmetrically. During the sucking a sustained muscle activity is present in the chin muscle, in the neck muscles and in the biceps and quadriceps muscles.

state 3 and rests on his right side; small changes in the head position take place and have their correlate in an increasing and decreasing activity of the neck muscle. In fig. 5.5-4 and 5.5-5 during minute 32 the same baby becomes more active, and in minute 33 he starts crying, on top of a high tonic activity phasic bursts with each cry can be seen. In fig. 5.5.-6 during minute 34 the baby is pacified by gently putting a hand on his body. The crying stops, the baby is back in a quiet state 3 and a continuous muscle activity is present in the neck muscle.

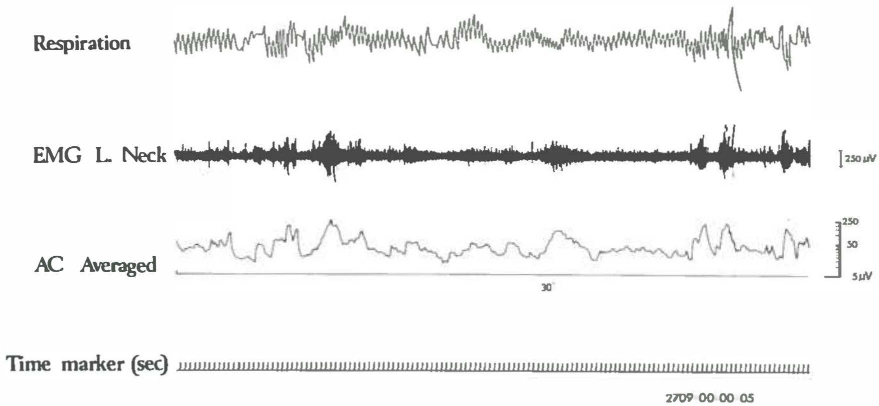


Figure 5.5.-3. Figures 5.5.-3, -4, -5, -6 and Figures 5.5.-8, -9, -10, -11, -12, are all samples of a playback of the respiratory signal, the EMG of the left sternocleidomastoid muscle and of the averaged signal of this EMG in the same newborn (aged 5 days) lying on his right-side.
In figure 5.5.-3. the newborn is in state 3 small changes in the head position take place, note the presence of an ungoing basic level of muscle activity (compare with fig. 5.5.-8).

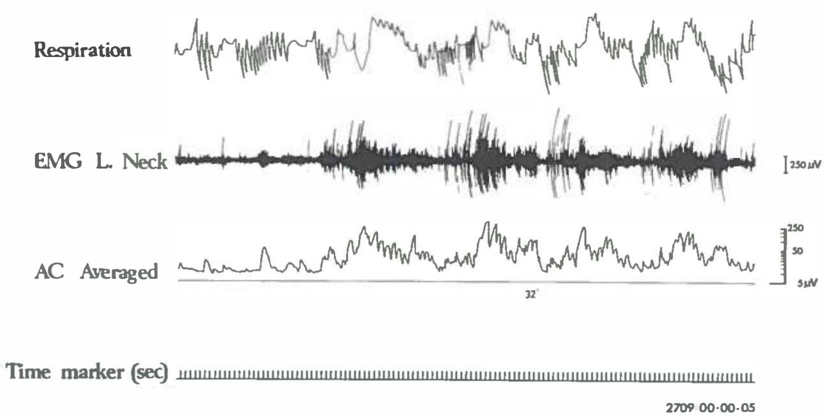


Figure 5.5.-4. The same newborn as in fig. 5.5.-3 (see legend). The baby is in state 4.

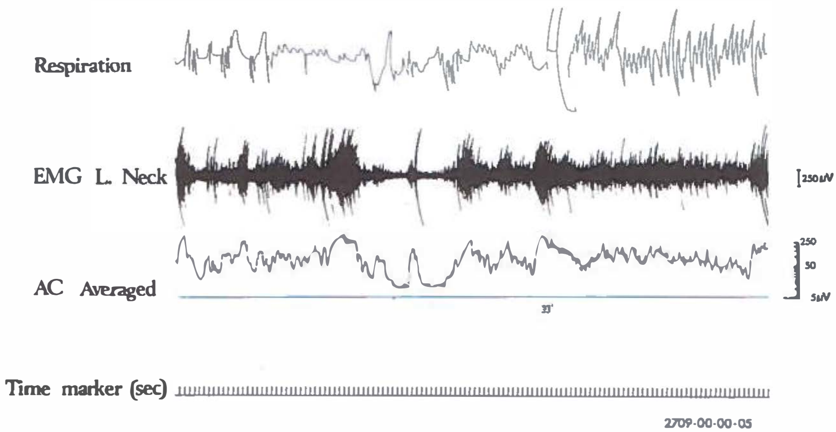


Figure 5.5.-5. The same newborn as in fig. 5.5.-3 (see legend). The baby is in state 4, at minute 33, he starts crying (state 5).

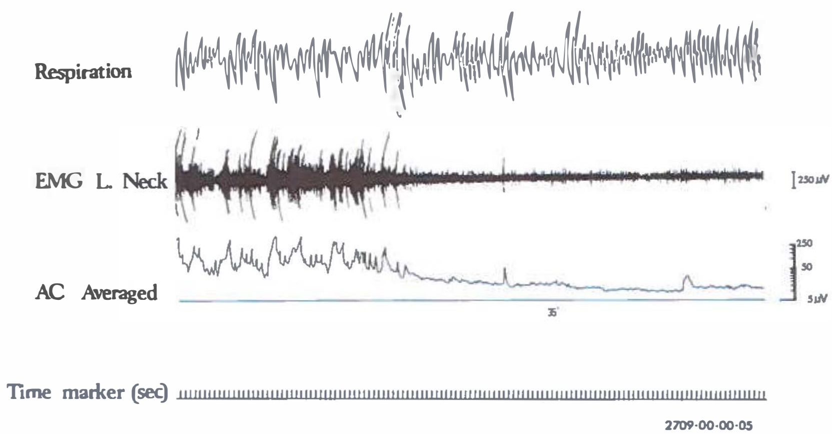


Figure 5.5.-6. The same newborn as in fig. 5.5-3 (see legend). The crying baby is pacified in the 35th minute, he returns in state 3.

The factor by which the highest tonic level in state 3 is higher than the lowest tonic level in state 2 was determined in four babies (O'Brien, et al., 1975). In these four babies seven comparisons between state 3 and state 2 were possible for both sternocleidomastoid muscles. For the upperlying sternocleidomastoid muscle the median of those factors is 9, five values range between 5 and 10,one low value of 1 and one high value of 15 is observed. For the underlying sternocleidomastoid muscle the median is only 1.7, the extreme values are 1 and 4. For the chin EMG this factor varies between 1 and 10, with a median of 3.
Using the same EMG technique Schloon et al. (1976) demonstrated that the amount of time in which tonic activity is present in the awake newborn is higher in the chin and sternocleidomastoid muscles than in the extremity muscles.

It looks thus that the awake newborn starts his movements out of an active posture. The movements are, however, still brisk and sustained postures are still very rare with two exceptions : the sustained head postures which are reflected in the high activity of the neck muscles and the sustained alert facial expression of the baby which is reflected in the chin muscle EMG. A third sustained "posture" should be presumed to exist in the intercostal muscles favouring the regular respiratory movements observed in the quiet awake newborn.

5.5.3.3. *The disappearance of the active posture at the onset of sleep and its electromyographical correlate*

During the behavioural descriptions in the present study the disappearance of an active posture at the onset of sleep has been documented at several occasions, this disappearance is the easiest to evaluate by looking at the changes in head position during the transition to sleep in sitting and in supine lying babies.
The physiological correlates at the onset of sleep are illustrated in figure 5.5-7. This awake newborn keeps his face slightly to the left side, a strong activity in the right sternocleidomastoid muscle is visible. At the transition to sleep the face glides in three steps further in a full left side resting position ; a stepwise decrease, twice followed by a reactive increase in muscle activity, is clearly visible in the right neck muscle. A decrease is also visible in the left neck muscle and in the chin muscle. This example illustrates also very clearly that at the same moment when the sustained muscle activity disappears the respiration, which is regular in quiet state 3, becomes irregular. This association of tonic activity in the EMG and regular respiration is confirmed in a new series of recordings (Schloon et al., 1976).

5.5.3.4. Postural behaviour and muscle activity during sleep

State 2 :

From our behavioural observations, especially from the observations on postural behaviour during imposed positional changes, our hypothesis is that no or a minimal sustained tonic activity would be present in state 2. This assumption proved to be correct since in all technically good recordings of the present study the lowest level of ongoing activity of all behavioural states was recorded during the epochs without movements in state 2. The level of tonic activity was not only minimal outside the phasic activity but even between two phasic bursts, the level drops immediately very low, this in contrast to the ongoing tonic activity with superimposed phasic bursts which was observed in the awake states. Fig. 5.5-8 and fig. 5.5-9 are illustrations from these phenomena in the upperlying sternocleidomastoid muscle of a 5 day old newborn resting on the right side.
As discussed before part of the gross-body movements in state 2 are considered as repositionings, this is most suggestive for the babies sitting in the baby-seat. The remaining question is, whether after such a repositioning a tonic activity reappears ? From the EMG recordings (as illustrated in fig. 5.5-8 and fig. 5.5-9) it can be seen that such movements which consist of strong phasic activities, are not followed by long lasting tonic activities. The disappearance of the muscle activity after such a phasic event is very steep in state 2 (see fig. 5.5-8 and 5.5-9) as compared with state 1 (see fig. 5.5-11 and fig. 5.5-12). This decay of the muscle activity to the zero (noise) level after phasic events is the topic of a detailed study by O'Brien et al. (1975).

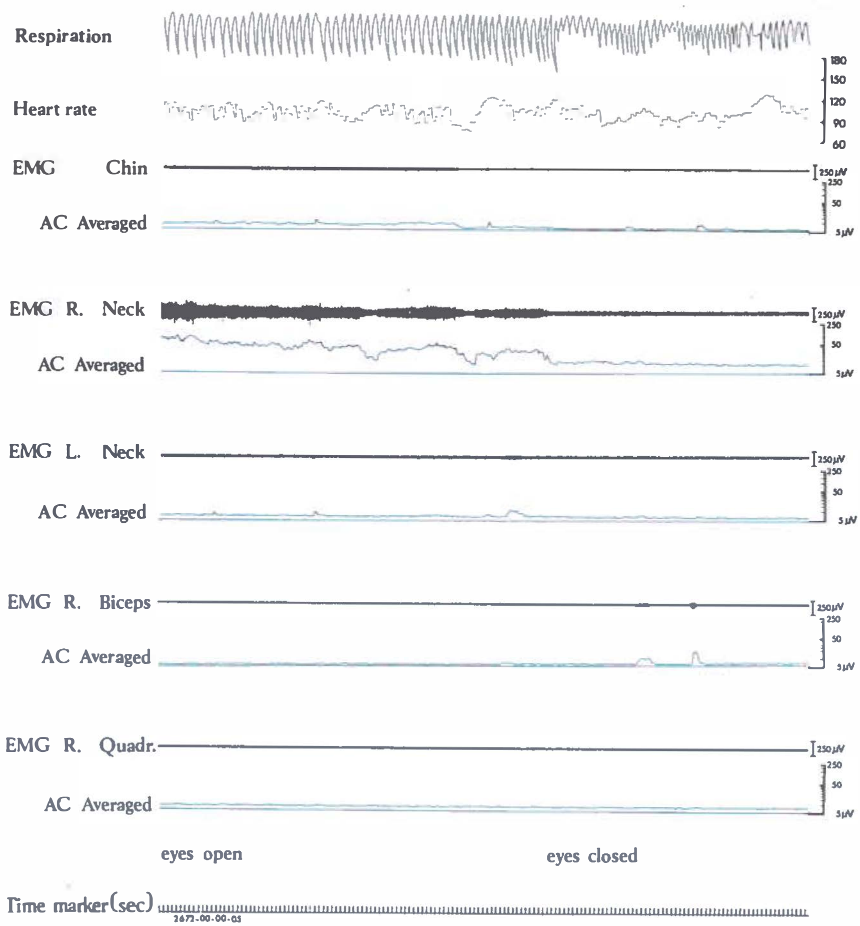


Figure 5.5.-7. Sample of a polygraphic recording showing the decrease of postural tone at the transition from state 3 into state 2 (same baby as in fig. 5.5.-2). The baby is in supine, the face is to the left. The decrease in tonic activity is most pronounced in the stretched right neck muscle, namely the Sternocleidomastoideus muscle. Note the change in the respiration at the same moment in which the EMG activities decrease.

During the observations of babies with their heads resting in the head holder, with or without rocking, small brisk head movements and even isolated contractions of the sternocleidomastoid muscle could be seen. From the observations of newborns in the side position it is known that babies in state 2 in the side position make frequently upward directed head movements, that are head-movements away from the surface of the bed. An EMG correlate of such a brisk small head movement is displayed in fig. 5.5.-8. After the short phasic burst, there is a 9 seconds lasting low

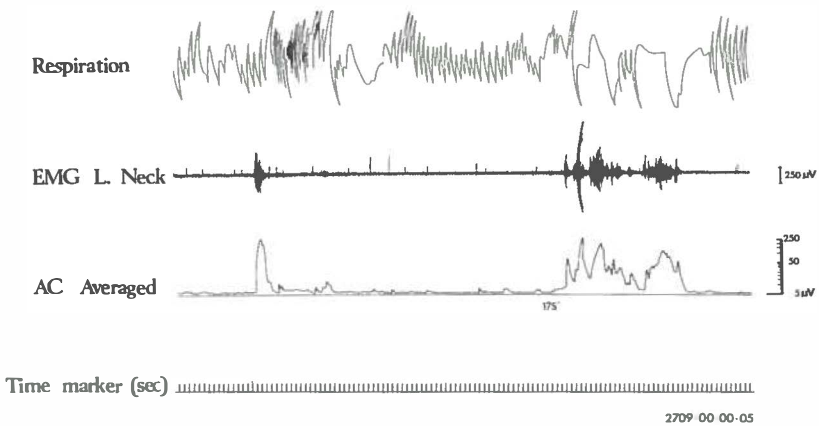


Figure 5.5.-8. The same newborn as in figure 5.5.-3 (see legend). The baby is in state 2, a small brisk head movement takes place in the 175th minute, a gross-body movement occurs just after minute 175. Note the abscence of an ongoing basic level of muscle activity in between movements.

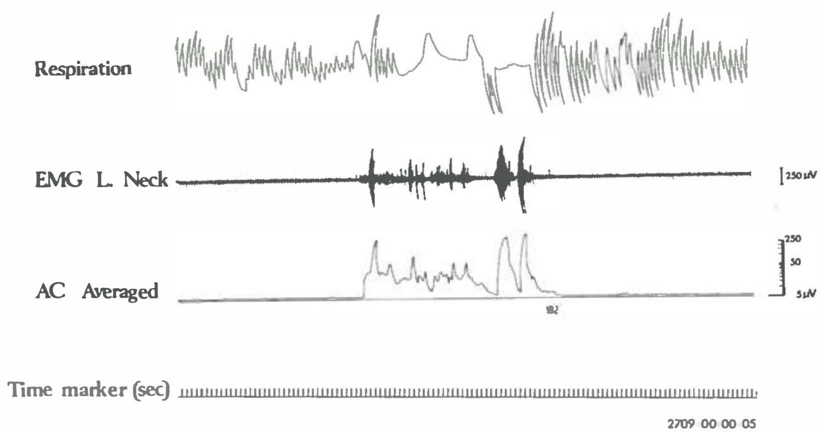


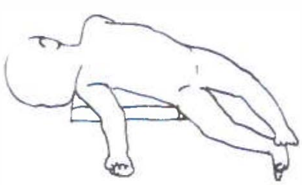
Figure 5.5.-9. The same newborn as in fig. 5.5.-3 (see legend). The baby makes a gross-body movement in state 2. Note the steep decay of the muscle activity at the end of the movement (compare with fig. 5.5.-11,-12).

level tonic activity ; does this after-discharge in state 2 reflects the response to an input from the vestibular or the neck joints ?
Schloon et al. (1976), after a detailed analysis of all phasic muscle activities during 21 H 30' of state 2 in 4 newborns could demonstrate that such phasic activities are more frequently observed in the upperlying than in the underlying neck muscles. Schloon et al. (1976) could also demonstrate that the longest tonic activity in state 2 never lasts longer than 30 seconds.

From these first series of behavioural-electromyographical correlates it appears that in state 2 the newborn's posture does not result from an on-going muscle activity. The gross-body movements do not elicit long lasting low levels of tonic activities. The actual posture in state 2 is the result of the orientation, the visco-elastic properties of the tissues and of the readjusting effect of the last preceding gross-body movement.

State 1 :

At the transition from state 2 into state 1 newborns make frequently gross-body movements, in the baby-seat they result most obviously in postural readjustments. In recordings with the improved surface EMG it was a consistent finding that these phasic activities resulted in a stepwise increase in the ongoing tonic activity, an example is given in fig. 5.5-10.
In state 1 during the observations of newborns in the various positions used and during the imposed positional changes the striking stability of the posture was the main finding. Casaer et al. (1973) suggested that this postural stability might be the result of an overall increase in the sensitivity of the muscle receptors to stretch, i.e. to postural load. Therefore an attempt was made to increase the stretch on a muscle without the need of touching, since this would also lead to an exteroceptive input. To stretch the sternocleidomastoid muscle a pillow was placed underneath the shoulder and indeed in state 1 a relatively stronger tonic activity was seen in the upperlying than in the underlying sternocleidomastoid muscle. A comparison with state 2, however, was not possible since in state 2 during a gross-body movement the three babies, in which this procedure was tried, placed their underlying arm underneath the head and by this postural adjustment the babies arrived in a comforable resting position.



State 1

State 2

This experimental attempt is a beautiful example of how the newborn uses different strategies according to his behavioural state to control his body posture. With this experience the last three babies were placed in the side position, without a pillow, since the possibility of a stronger pull on the upperlying sternocleidomastoid muscle by the head on the shoulder existed anyhow in this position.

In all three recordings the relative increase in the level of tonic activity was higher in the upper than in the lower sternocleidomastoid muscle. The factor by which the highest level in state 1 exceeded the lowest level in state 2, ranged in our last three recordings between 2 and 7 for the upperlying neck muscles and between 1 and 5 for the underlying neck muscles. O'Brien et al. (1975) after a comparison of twenty states 1 with twenty states 2 in five newborns came to the following results for the factors

by which the highest tonic level in state 1 exceeds the lowest level in state 2 : for the upperlying sternocleidomastoid muscle the median of the factors is 4.0, the ranges are 2.5 to 7; for the underlying the median is 2.5 and the ranges are 1.6 tot 3.6. Only in one out of 20 states 1 studied the factor is higher in the lower lying than in the upperlying sternocleidomastoid muscle.
Besides these differences between state 1 and state 2, clear differences in the level of tonic activity do occur inside a state 1. These upward or downward modulations of the level of tonic activity are temporally related to phasic EMG activities (see fig. 5.5-11 and -12). The behavioural correlates of these phasic EMG activities in state 1 are startles, sighs, mouthing and small changes in the head position. Increases in the level of tonic activity are always related to such phasic events, decreases may be related to phasic events or occur "spontaneously" (Schloon et al. 1976). The decay of the muscle activities after a phasic event in state 1 is gradual and, as previously mentioned, these decays are less steep in state 1 than in state 2 (compare the decay in state 1 in fig. 5.5-11 and -12 with the decay in state 2 in fig. 5.5-8 and -9).
For some of the long-lasting "spontaneous" changes in the level of tonic activities, a behavioural correlate could be traced with the time-lapse photography. After a startle sometimes the newborn did not return immediately to his previous posture, but a fore-arm, or a foot was kept a few millimetres above the bed-surface. These antigravity postures lasted more than a minute at several occasions even more than 3 minutes. A very gradual lowering of the extremity found its correlate in a "spontaneous" decrease in the tonic activity, the occasionally observed acceleration in such downward movement was reflected in the more abrupt downward modulations of the tonic activities.
Schloon et al. (1976) after a detailed quantitative analysis of tonic activities and their modulations during state 1 could demonstrate that the percentage of state 1 time with tonic activity is the highest in the chin muscle (85%), then in the sternocleidomastoid muscles (41%), then in the arm muscles (about 15%) and finally the lowest in the leg muscles (about 10%). Furthermore, these authors demonstrated a high degree of synchroni-

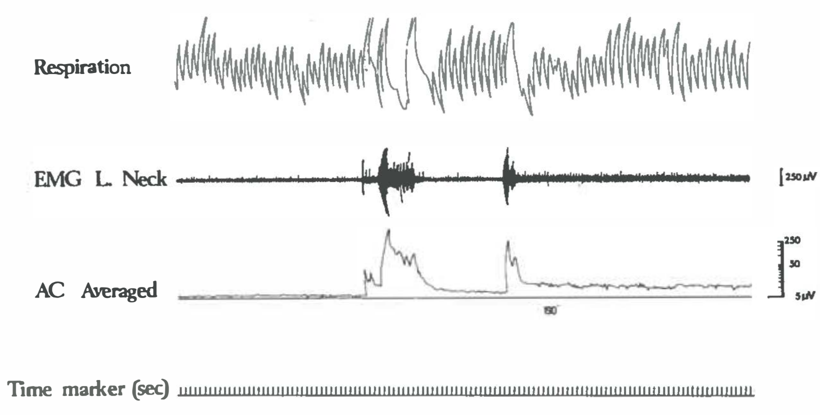


Figure 5.5.-10. The same baby as in fig. 5.5.-3 (see legend). Sample of a transition from state 2 into state 1. Note the stepwise increase in the basic level of ongoing muscle activity.

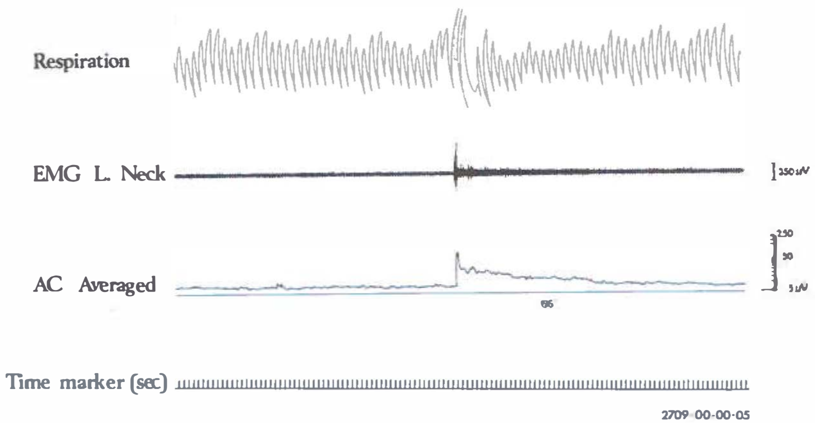


Figure 5.5.-11. The same baby as in fig. 5.5.-3 (see legend). Sample at the occurrence of a jerk in state 1. Note the gradual decay of the EMG activity after the Jerk. (compare with fig. 5.5.-8, -9.).

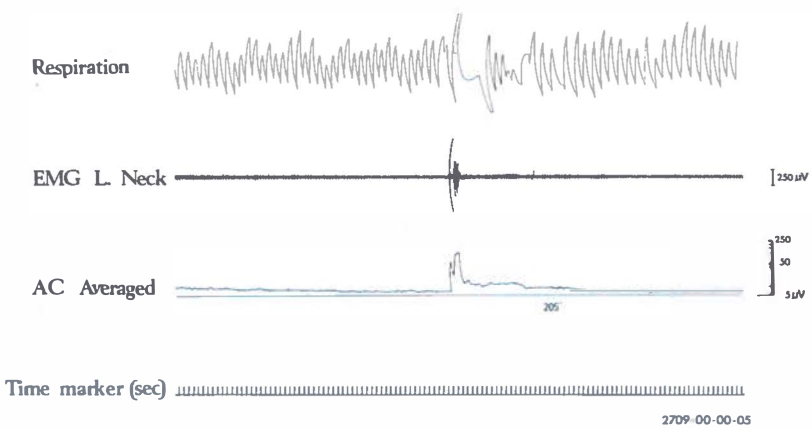


Figure 5.5.-12. The same baby as in fig. 5.5.-3 (see legend). Sample at the occurrence of a jerk, followed by a small head-movement in the last minute of state 1. Note the lower level of muscle activity at the end of state 1 in this baby (compare with fig. 5.5.-10, -11).

zation during state 1 in the phasic events between the chin muscle and the other muscles studied; these synchronous phasic activities were slightly higher for the sternocleidomastoid muscles and the arm muscles than for the leg muscles.

From these first series of behavioural-electromyographical correlates it appears that in state 1 the newborn's posture results from ongoing low levels of muscle activities. A cephalo-caudal gradient seems to exist. The actual height of the tonic muscle activity is determined by the stretch on the muscle, i.e. by the postural load.

5.5.4. Concluding remarks on postural behaviour and muscle activity in newborn infants

In this section changes in postural behaviour could be directly related to changes in muscle activities recorded with an improved surface EMG technique.
From the analysis of the EMGs and their averaged signals it may be concluded that the newborn uses different strategies to control his body posture according to his behavioural state. Postural mechanisms responsible for these differences have been touched upon in this section and they will be further elaborated in the next chapter.

Chapter 6

GENERAL DISCUSSION

From these results, it is fair to conclude that with certain restrictions the newborn has a posture and displays a postural behavioural repertoire. The interacting factors determining the actual posture and the ongoing postural behaviour are the main topic of the present discussion; these factors are position, behavioural state and previous postural behaviour.

6.1. POSITION IN SPACE - POSTURAL CONTROL

In the baby-seat, i.e. in a semi-upright position, the newborn moves more and for longer than in the horizontal position; in supine he moves more than in prone. These total body movements, especially those occurring in the baby-seat, are very suggestive of being postural resets. In the vertical position, especially, when the newborn is carried, he makes head movements about a vertical axis and attempts to look around. Head-lifts in the lying position occur frequently in prone, occasionally in the side, but never in the supine position. Startles appear in prone as stirring movements, whereas in supine they are large amplitude movements.

In terms of neural mechanisms the summarized facts indicate that the newborn is really capable of perceiving his position in space and of reacting differently according to his orientation. Thus, the minimum requirements for a postural control system already seems to exist in the newborn, i.e. a set of receptors, afferent fibers, central connections, motoneurones, efferent fibres and muscles.

6.1.1. Structural aspects of the postural control system

In a series of recent review papers, the available knowledge has been summarized on prenatal development of receptors and on early development of motor control in the human (Mastaglia, 1974, Schulte, 1974, Wright, 1974, Bradley and Mistretta, 1975 and Wijke, 1975).
General agreement exists that in the full-term the vestibula, the muscle-spindles, the Golgi-tendon apparatus and the Meissner and Pacinian corpuscules are at the level of functional maturity. The presence of muscle-spindles in the neonate (Voss, 1937, Voss, 1959) does not mean that they have the same structural maturity in all muscles. A cephalo-caudal maturation still seems to occur postnatally for both the muscle spindles and for the various joint- and skin-receptors (Humphrey, 1964). As to the afferent and efferent fibers both myelinisation and growth of the internodal distance continue after birth. Due to the small size of the neonate this has no strong bearing on neural functioning in neonatal life and early infancy, as can be evaluated from the constancy of reflex times in early life. (see Schulte 1974).

No data are available as to the maturity of the motoneurones, the relation between the maturity of motoneurones and interneurones, and on the structural organisation of the alpha and gamma systems in the neonate.
Knowledge about the developmental anatomy of spinal and supraspinal interaction in the neonate is almost completely limited to an accurate timetable of the myelinisation of intersegmental and long neuronal tracts and to histological studies on the dendritic arborization of various cortical and subcortical structures. A cephalo-caudal maturation exists for the spinal intersegmental tracts and for the supraspinal descending and spinal ascending tracts. The vestibulo-spinal tract matures before the reticulo-spinal and tectospinal tracts. In the spinal cord of the full-term most ascending and descending tracts are myelinated with the exception of the lateral pyramidal tract.
In the pons, the middle cerebellar peduncle is not myelinated. This corresponds to the incomplete myelinisation of the lamellae of the cerebellar hemispheres at this age. The cranial nerves are all myelinated in the full-term neonate with the exception of the olfactory bulbs. In the cortical-subcortical structures it is especially the corpus callosum and the fornix that are not myelinated at birth (Larroche, 1966, Yakovlev and Lecours, 1967.

Finally, it is well-known that the dentritic arborisation of the cerebral cortical layers is far from completed at birth. The motor cortex and the sensory-motor cortex are more mature than areas situated more frontally or parieto-occipitally. In the motor and sensori-motor cortex those areas that are related to the trunk show the highest degree of cellular differentiation (Rabinowicz, 1964, Larroche, 1966).

Further histological studies in the human on the maturation of the cerebellum, the olive and other supraspinal centers have been carried out (see Robinson and Tizard, 1966, see Schulte, 1974). Differences, however, in the techniques used and the fact that many structures have not yet been studied at all, make it impossible to give a comprehensive neuro-anatomical picture as to the supraspinal organisation in the neonatal period.
Chemical indices of structure, such as DNA-content for cell number and myelin-lipid content for myelinisation are used to study brain growth. Dobbing (see review 1974) demonstrated that cell number in the human brain increases until the second year and that the cerebellum has a late but fast growth spurt from immediately before birth until the 15th postnatal month. A critical and comprehensive review of the available neuroanatomic data by an authority in the field would be an enormous help for developmental neurologists. At present the available data on developmental neuroanatomy do not allow us to construct a blue-print on the basis of which behavioural and neurological hypotheses could be designed and subsequently tested.

6.1.2. Functional aspects of the postural control system

Beside these neuro-anatomical data some neurophysiological studies in the newborn might help us to understand why and how the newborn is capable of reacting differently according to his position in space.
The alpha and gamma systems in the newborn have been studied by comparing the H-reflex as an index of spinal alpha motoneuron excitability, with the T-(tendon tap) reflex as an indication for the level of activity in the fusimotor system (Thomas and Lambert, 1960, Blom et al. 1964, Mayer and Mosser, 1969 ; Stefanova-Uzunova, 1972 and Mayer and Mosser, 1973). Both the H- and the T-reflexes are present in the newborn. When the H-reflexes are compared with the T-reflexes in the same muscle, a stronger T-response

is consistently found in infancy, this in contrast to the findings in children and adults where the H-reflexes are stronger. This neurophysiological finding might indicate an increased fusimotor activity in young infants (Stefanova-Uzunova, 1972); it parallels the behavioural observation that in the newborn, both awake and in state 1, cloni are frequently observed.
The study of the influences of paired electrical stimuli or of post-tetanic facilitation on the H-reflexes shows clear differences between newborns and adults. This finding points towards a different organisation of spinal and supraspinal control of alpha motoneuron excitability. Cephalocaudal differences in the H-responses were found during the early postnatal months, responses in the hand muscles being more mature than those in the foot muscles (Mayer and Mosser, 1973). Several authors (see discussion in Mayer and Mosser, 1973) could demonstrate that early in infancy the H-responses can be easily elicited in the hand muscles and in the finger muscles. This, however, becomes more and more difficult after six months of age. It is interesting to note that at that age the direct cortico-spinal tracts become functional, as reflected in the appearance of finger pointing and pincer grasping.
Results of systematic studies on tonic myotatic reflexes in the newborn (such as the recoil reflexes of arms and legs) are difficult to interpret as to the underlying neural mechanisms. Attempts to extrapolate from these results to possible differences in the functioning of the static and the dynamic gamma motor system are hazardous. In vivo, it is never possible to apply a pure myotatic stimulus without applying at the same time exteroceptive and arthrokinetic inputs. Therefore the increased tonic activity found in the present study in the upperlying sternocleidomastoid muscle in the newborns lying in the side position is an interesting observation. It proves that long-lasting tonic activities resulting from stretch occur in the newborn also without an extra tactile stimulus. It should, however, be clear that even in this experimental condition arthrokinetic inputs from neck- and shoulder-joints or even vestibulo-spinal influences can not be excluded.
Tonic myotatic responses in the muscles can only be recorded consistently after the 34th week postmenstrual age. The responses in the flexor muscles are stronger than in the extensor muscles between the 34th and 40th week of postmenstrual age (Schulte, 1974). This author speculates that a temporal difference in the development of the gamma muscle-spindle-system might exist between the flexor and the extensor muscles. In animals both primary and secondary endings have an excitatory influence on flexors, and only the primary endings have an excitatory influence on the extensors, since an inhibitory neuron is placed between the secondary ending and the extensor motoneuron. It could be that this model would be applicable to the neonate, but at present the hypothesis can not be tested.
For this discussion one can conclude that it seems plausible from neurophysiological studies that both, the alpha and the gamma system, the muscle-spindles with their afferent and efferent fibers are functioning at birth. The result of the systematic studies on skin reflexes in neonates (Prechtl et al., 1967, Vlach, 1968) make it plausible that the newborn utilizes, besides proprioceptive information, also exteroceptive information of superficial and deep skin receptors to perceive his position and his positional changes in the three-dimentional space.

Before the discussion of other mechanisms involved in postural control is continued a few comments will be made on the maturation of the motor-end-plate, an essential link in all input-output loops. In the study of Schloon et al. (1976) and in the present study, the best sustained tonic activities are recorded in the chin and in the neck muscles. Furthermore, a sustained

output in the respiratory muscles can be concluded from the sustained regular breathing in the quiet awake state 3 and in state 1. This is interesting since the neuromuscular synapses of the tongue, the diaphragm and the intercostal muscles are highly differentiated at term, whereas in the extremities (especially in the muscles of the foot) the complex endplate has not matured (Humphrey, 1964).
Neurophysiological studies in the newborn on post-tetanic facilitation and post-tetanic exhaustion indicate that in the newborn and especially in the premature the neuromuscular junction is not fully mature ; the myo-neural reserve, i.e. the acetylcholine quanta are either low or cannot be produced sufficiently quickly to allow sustained responses to supramaximal trains of electrical stimuli (Koenigsberger et al., 1973, see Schulte, 1974). This peripheral neuromuscular maturation, as an explanation for some changes in early behaviour, deserves more attention in further studies.

So far more or less segmental input-output mechanisms in the neonate have been discussed. During the present study, however, it became clear that newborns use intersegmental programmes to adapt and to correct their posture. When an arm or leg is lying in an odd position the newborn re-aligns this extremity with the help of total body movements. The existence of intersegmental programmes in the newborn is also well illustrated by the first attempts to locomote and to crawl and they can be studied systematically in complex responses such as, among others, the Galant response and the Bauer response.
The vestibular system with its afferent and efferent pathways to the cerebellum, and with its ascending and descending spinal pathways, seems already very mature at birth (Humphrey, 1969). Vestibulo-ocular responses to caloric stimulation and ocular responses to rotation are present in the neonate (Barany, 1918, Groen, 1963, Von Bernuth and Prechtl, 1968 and Eviatar et al., 1974).
In the present study babies lift their heads in prone and in the side position. If head-lifts last long enough the head is brought into a vertical position, i.e. the line connecting inion and nasion is brought into the horizontal plane. For the correct orientation of the baby's head in space an interaction between vestibular and neck proprioceptive information is mandatory. It seems impossible to separate the relative contributions of either vestibular or neck proprioceptive influences in such postural behavioural programmes. In the present study series of vestibulo-palpebral responses are observed when the baby, sitting in the baby-seat, makes small head-movements. It is impossible to decide whether this response results from the vestibula, from the neck joints or from an interaction of both. Gregg et al. (1976) studied the relative effect of a combined vestibular-proprioceptive stimulus, namely displacements along a longitudinal axis, compared to the effect of being in the horizontal or in a semi-upright position. Taking the quality of tracking eye-movements as a parameter to differentiate these various effects, the authors could demonstrate that the combined vestibular-proprioceptive stimulus is the most effective in enhancing visual pursuit and scanning eye-movements. Once more in this study it was not feasible to differentiate the factor vestibular input from the factor proprioceptive input.
To solve this problem, which has not only theoretical implications but could also be relevant for the clinical situation (namely for the study of the development of abnormal postural behaviour), a further experiment could be designed : H-and T-reflexes should be studied in upper and lower extremities under the following experimental conditions : a. during caloric vestibular stimulation, i.e. a pure vestibular stimulus; b.during longitudinal rocking of head and body, i.e. a mainly vestibular stimulus but neck proprioceptive input cannot be excluded; c. during longitudinal rocking

of the body with restriction of head movements, i.e. a proprioceptive stimulus mainly of the neck but here some vestibular input can not be excluded. In such experiments an accurate recording of eye movements and of neck muscle EMG activity would be required since they are physiological correlates of very sensitive outputs to vestibular and neck proprioceptive inputs.

Until now, most postural behaviour is explained by control systems that are postulated in the spinal cord and in the medulla . As Schulte (1974) indicated, this may well be the result of the fact that a great wealth of data on spinal function has been accumulated since Sherrington's basic experiments, thus allowing detailed models of motor control at that level to be constructed. In contrast, the limited knowledge of neuro-physiological mechanisms of higher motor control, even in animals, may well have led to an overestimation of the significance of the spinal cord for neonatal motor functioning.
In recent mainly psychological work a series of experiments relating to higher control functions in neonates and very young infants was described (see Bower, 1974). Newborns are demonstrated to show depth perception towards optical and acoustical stimuli (Ball an Tronick, 1971, Bower, 1974). These results, however, are so new and the experimental data are derived from such small numbers of newborns that further studies to confirm or to reject these results are necessary. Especially detailed descriptions should be given of how the experimentators try to control for inputs from other sensory modalities such as vestibular and neck-proprioceptive inputs. If not, the danger exists that responses and complex behaviour in the neonate will be interpreted as the result of higher control functions although they could be explained perhaps on tegmental, midbrain or even brainstem level. Observing a newborn interacting with his care-giver is very suggestive for accepting higher control functions to exist in the newborn. However, the neural mechanisms underlying such a control must still be discovered.
The existence of somatosensory evoked responses in the neonate and in young infants shows only that information reaches the cortex (Hrbek et al. 1968, see Desmedt 1973 and Faienza, 1976).

6.2. POSTURAL BEHAVIOUR AND THE BEHAVIOURAL STATES SUPRA-SPINAL MECHANISMS

The findings in the present study, that newborns are more often awake and for longer in the baby-seat, may be reason to suppose that mechanisms controlling the behavioural states and which are probably situated above the medulla are influenced by postural behaviour and may even have an influence on postural behaviour.
Further arguments for these higher control mechanisms will be derived from the discussion of the second factor determing the actual posture of the newborn, namely that in a given position postural behaviour is largely determined by what the baby is actually doing.

This is most obvious during feeding and non-nutritive sucking. The postural behaviour during sucking and the physiological concomitants of this behaviour, especially the EMG recordings, demonstrate that drinking is not only a perfect coordination of mouthing, sucking, breathing and swallowing, but that drinking is a total behavioural programme including a very characteristic and mature postural sub-programme.
Several authors such as Wolff and White, (1965) and Gregg et al., (1976) demonstrated in infants older than two weeks enhanced visual alertness and

improved visual pursuit and scanning eye movements during sucking. It might well be that this increased alertness is the result of, or is at least paralleled by a change in body posture. At several occasions during the present study the antigravity posture of the newborn baby increases and the baby's posture seems frozen at moments of visual or acoustical orienting. Wolff (1959) described as a separate state the state of "alert inactivity" in the awake infant. From the results so far obtained with the surface EMG recordings the hypothesis is that during such periods of alertness long-lasting activities will be present in the neck and the facial muscles.

In contrast, at the onset of sleep, newborns lose their antigravity postures. This phenomenon is most obvious in newborns sitting in the baby-seat and lying horizontal in the supine position, since in these positions the gravitational load is the highest. From the present observations the transition from the sleep states to the awake states can be summarized as the reassuming of an active antigravity posture.
Newborns do not only change their postures and postural behaviour at the transitions from waking to sleeping states or vice versa, but also during sleep consistent differences in postural behaviour and body postures are observed. A meaningful description of these differences is only possible if one considers that behavioural states and behavioural state-cycling exist during sleep.
In state 2, the periods without gross-body movements can be described as the absence of antigravity posture; this is most obvious in the sitting babies. The absence of an active posture in state 2 is clearly demonstrated during the experiments with the transversal rocking. The newborns slide away during such periods. No or a minimal activity in the EMGs is recorded in quiet episodes during state 2.
In contrast, the total body movements in state 2 are similar to the active movements in the awake baby. These movements result in changes in orientation, in readjustments of odd postures, in short head-lifts and in displacements. They differ, however, because they end abruptly . Also the EMG-correlates show a very steep decay to a zero or noise level activity at the end of a movement in state 2. Even during the ongoing activity the level of the EMG drops from very high to very low, there is no ongoing activity on top of which the phasic activites are super-inposed, as is seen, in the awake states. All these interfering movements during state 2 result in a very unstable posture. This is most obvious in the study in which spontaneous head-movements are systematically studied with the help of the head movement recorder.
In state 1, the picture is totally different, the newborn's posture is stable, this is most obvious in the sitting babies. The baby is capable of controlling his posture within certain limits on the rocking platform. The co-ordinates of the head posture in the experiment with the head-holder are surprisingly stable over time. The head-following movements as a consequence of imposed body movements are very precise. The EMGs show low levels of long-lasting muscle activities. When a movement in state 1 occurs, it is mostly a startle. A startle, although involving the total body, has a minimal effect on the stability of the body posture; since after a startle the pre-startle body posture is reassumed.

In the present study the very close relation in time between posture and behavioural state is so obvious that one might say that posture and state could be the same or that one is prerequisite for the other. The first part of the statement does not explain anything in terms of neural mechanisms. The second one is not correct, since babies in state 2 with an arm lying in an odd position frequently show gross-body movements, and just after a movement resulting in a realignment the transition to the next state 1 is frequently observed. This gives the impression that a certain posture has to be achieved before a transition into state 1 is possible. There are, however, babies who, after a series of unsuccessful gross-body movements, change into state 1 without realignment of the odd lying extremity, and then it is amazing to observe that during 15 to 25 minutes the baby remains in the same odd posture. Immediately after the next transition from state 1 into state 2 attempts to correct this odd posture appear.

In adult cats a similar strong relation in time between postural behaviour and the state of the animal was previously described by Van den Hoofdakker (1966). The author speculated "this probably means that the different behavioural states represent different states of organisation in the neural mechanisms regulating posture". It is not my intention to tie Van den Hoofdakker's findings and the present findings immediately to something like the reticular activating system, but it might be more interesting to place the results in the context of a whole series of experiments related to midbrain functioning in animals (Hess and Weisschedel, 1949, Hess, 1951, and see Van den Hoofdakker, 1966). These studies point to the existence in animals of an area in the frontal part of the midbrain which contains neurons responsible for lifting and lowering the head and the frontal part of the trunk. Hassler (1956, quoted by Van den Hoofdakker 1966) pointed out that this system is tonically active during wakefulness. In a more recent study of Spyer et al. (1974) it was demonstrated that in the reticular formation there are neurons that show clear "gravity" responses. These responses in the experimental situations had the vestibulum as their input channel and were sensitive not only to the changes in position but also to constant orientations in space.

With the available knowledge of the human neonatal nervous system, it is impossible at present to try to extrapolate from these data in adult cats to the postural control system in the human neonate. It is, however, plausible that also in the neonate supraspinal centers, which are involved in the regulation of posture, are very tightly linked to those centers that are regulating the behavioural state cycling. The localization of these centers, and even more the organisation of the circuits in which these centers are lying, are still unknown in the newborn. It cannot be excluded that centres higher than the midbrain are involved in this regulating system, since it is known from recent histochemical studies on the adrenergic and dopaminergic circuits during prenatal human brain development that connections or projections from the midbrain to the cortex are present long before term (Seiger, 1975).

6.2.1. Supraspinal descending influence ?

How is the activity in the final common pathway, i.e. the activity of the alpha motoneurones resulting in muscle activity, influenced by the supraspinal regulating centers, wherever they might be situated ?
From neurophysiological experiments in animals the existence of several ways of supra-spinal modulation has been established. A first way is the direct modulation of the activity level of the alpha motoneurones, by presynaptic activation or inhibition. A very similar effect, without direct contact with the alpha motoneurones, can be obtained by modulating the activity of interneurones and their inhibitory influences on the alpha motoneurones. A second way is a supraspinal control of incoming sensory inputs; this can be achieved by presynaptic inhibition of the alpha motoneurones,but also by influencing those interneurones that are situated between endings of afferent pathways and alpha motoneurones. A third cate-

gory is a direct supraspinal influence on the peripheral receptor. The best studied model is the supraspinal control of the gamma system for setting the sensitivity of the muscle spindles. In animals gamma motoneurones are smaller than alpha motoneurones and therefore they are easier to depolarize. A supraspinal drive of gamma motoneurones resulting in a higher sensitivity of the spindles leads to a continuous inflow in the spindle afferents. This input would be sufficient to drive the relatives smaller tonic alpha motoneurones. A low level of muscle activity in the extrafusal fibers would thus be the final result of a supraspinal drive of intrafusal fibers. This model is postulated for "holding" functions in motor control such as sustained postures (Granit, 1970, Granit and Burke, 1973). More recently alpha-gamma coactivation has been demonstrated during voluntary movements in man (Vallbo, 1971). This model could be more appropriate to serve other motor programmes such as orienting behaviour. The absence of gamma coactivation can be considered as a true inhibition (Granit, 1970).

The absence of an antigravity posture and the minimal muscle activity during quiet episodes of state 2 can be explained by a direct inhibitory influence on the alpha motoneurones. In adult cats such an inhibitory influence on the alpha motoneurones during REM-sleep does exist (Pompeiano 1967). Hodes and Dement (1964) demonstrated that in adult man during REM-sleep H-reflexes and T-reflexes are weak. Also in human newborns a decrease of the H- and T- reflexes is found during REM-sleep (Hodes and Gribetz, 1962, Prechtl and Lenard,1967, and Mayer and Mosser,1973). In the newborn the low level of activity in the alpha motoneurones may thus result from a direct supraspinal depolarisation or from an indirect supraspinal effect on the gamma-alpha loop (see below).
A presynaptic inhibition on information coming from the peripheral receptors does not seem to exist in state 2. Newborns are capable to react to sound, to light, to exteroceptive and to vestibular stimuli in state 2 (see Prechtl, 1974). In the present study the babies correct their postures, and they show vestibulo-ocular and vestibulo-palpebral responses in state 2. They make head movements and show phasic activities in the upper sternocleidomastoid muscle. However, the tendon-reflexes are demonstrated to be at the lowest level in state 2 as compared to the awake state and state 1. Prechtl and Lenard (1967) demonstrated that in state 2 the intensity of the tendon reflexes shows a negative correlation with the intensity of the REMs.
Two mechanisms may be responsible for these observations, a presynaptic inhibition of the afferents from the muscle spindles, or a decreased gamma drive. Both phenomena do exist in the adult cat during REM sleep (see Pompeiano, 1967).
If one tries to explain the observed facts as simply as possible, then all the phenomena observed during quiet episodes in state 2 can be explained by a decrease in the gamma drive, resulting in a decreased depolarisation of the alpha motoneurones.
The origins of gross-body movements in state 2 are not understood at present. Are they the result of an endogenous rhythm ? (see Prechtl, 1974). In the present study at least a part of the gross-body movements appear like postural resets and are influenced, perhaps even elicited, by environmental factors. Whether the alpha motoneuron pool is further influenced during such movements by supraspinal control mechanisms is at present unknown. The low level of EMG activity just after and even during the movements in state 2 might be an indication that no alpha-gamma coactivation would exist during gross-body movements. Tendon reflexes and the exteroceptive reflexes are shown to fluctuate during state 2 (Prechtl et al., 1967). In an unpublished study, Vlach et al. (1970) found that

the responses to a recoil stimulus of the arms are enhanced if a gross-body movement occurs prior to the stimulus. These results indicated that some after-effect of gross-body movements on the input-output relations may persist. Further detailed studies with the improved EMG technique are required to understand the mechanisms underlying gross-body movements. Future behavioural or physiological studies should not only indicate whether the responses are obtained in state 2 but also how the temporal relation is between gross-body movements and the studied events.

In state 1 the baby's posture does not change during the whole state and the posture is almost not influenced by environmental factors, this is most obvious during observations in the baby-seat and during transversal and longitudinal rocking. The simplest model to organize this posture would be an increased drive on the whole gamma motoneuron pool. A more complex but also plausible explanation would be a small degree of alpha-gamma coactivation. The startles in state 1, which are very sterotyped and which involve the whole body, can be explained as supra-spinal triggered alpha-gamma coactivations. That a drive on the gamma motoneurones or an alpha-gamma coactivation does exist may be concluded from the observed antigravity postures after startles and from the very gradual returning towards resting postures with their EMG correlates, i.e. the slow decay of the muscle activities after startles.
Previous studies on exteroceptive, vestibular and acoustical inputs show the smallest responses in state 1 (see Prechtl, 1974). In contrast the tendon-reflex responses are very strong during state 1. The existence in state 1 of spontaneously occurring or elicited cloni, especially in the adductors of the legs, is a well established fact. All these findings and also the absolute regularity of the respiration (see below) are arguments for accepting that an increased drive on the gamma motoneurones exists during this state.
The presence of a presynaptic inhibition on afferents from sensory inputs in state 1 becomes plausible from the following observations made in the present study and obtained after reanalysing the polygrams of the study by Von Bernuth and Prechtl (1968). During rocking experiments and experiments while the head is fixed in a head-holder a short period of fussing occurs just at the transition from state 1 into state 2. This may indicate that at that particular moment the peripheral sensory input is suddenly again perceived by the newborn.

For the present discussion one may conclude that a supraspinal modulation of the gamma motoneurones is one of the mechanisms used in neonatal postural control. That a supraspinal presynaptic inhibition of sensory inputs and a direct supraspinal postsynaptic modulation of alpha motoneurones would exist is still speculation.

6.2.2. Posture and respiration

In the present study a very close relation in time between the stability of posture and the regularity of respiration is illustrated at several occasions. This is most obvious when the postural load is highest namely in the sitting newborns. The EMG correlates of this relation are the sustained levels of activity in the chin and neck muscles at the occasion of regular respiration in state 3 and in state 1 (see also Casaer et al., 1973 and Schloon et al., 1976). Prechtl (1968) demonstrated with quantitative analyses of polygraphic recordings lasting between 6 and 8 hours that the respiration is more regular in state 1 than in state 2 and that the respiratory rate is higher in state 2 than in state 1. Prechtl (1969) speculated that the regularity of the respiration may result from an increased gamma drive in the respiratory muscles during state 1. Hathorn (1974) using body-plethysmography confirmed these results, and this author demonstrated that in state 2 the tidal volume is similar to or smaller than in state 1. In the present study in the sitting babies the increased respiratory rates during state 2 and to a less extent during state 1 might well be explained by a further decrease of the tidal volume.

In recent studies on respiratory control of preterm and full-term human newborns a common point in the discussions is that the observed facts can not be explained only by changes in the chemical drive but that other (neural?) factors controlling the stability of the thoracic cage are important (Bodegärd, 1975, Rigatto et al., 1975, Kirkpatrick et al., 1976, and Tauesch et al., 1976). A similar conclusion, i.e. the relevance of neural factors, can be derived from recordings in the neonate with a newly developed transcutaneous O_2 electrode; since the variation in the O_2 tension can not be explained only by chemoreceptor-function or dysfunction (see Huch et al., 1975).
Results of studies on the maturation of the so-called "Hering-Breuer" reflexes vary widely according to the methods used, whether airway occlusion takes place at the end of inspiration or at the end of expiration. Some of the observed differences can be explained by accepting the existence of intrapulmonary stretch receptors, which are vagally mediated, and also the existence of chest-wall and intercostal receptors, which have their inflow via the dorsal spinal roots. The chest-wall reflexes are, at least in animal experiments, not influenced by vagotomy, but they are under the influence of the gamma control system (for studies in the newborn see Bodegärd et al., 1969, Bodegärd and Schwieler, 1971, Olinsky et al., 1974 a and b, and for animal experiments see Sears, 1973). Bryan and Bryan (1976) pointed to the somewhat forgotten fact that intercostal muscles are not only respiratory muscles, but that in man they have a role to play in the organisation of phonation, abdominal pressure and ... posture !
Duron (1973) and Haltunen (1974) stressed the differences in respiratory control between the intercostal muscles and the diaphragm. In anaesthetized animals the activity of the intercostal muscles, which have more spindles, is more sensitive to higher control centers, whereas the diaphragm is more sensitive to the chemically driven autonomous nervous centers. In dogs the intercostal muscles are more specifically influenced by differences in load, whereas the diaphragm is more sensitive to changes in CO_2 tension of the inspired air (Altose et al., 1975).

The understanding of possible neural mechanisms involved in the control of neonatal respiration received an enormous impetus from the rediscovery by respiratory physiologists of the behavioural state (see Comline et al., Foetal and Neonatal Physiology. - Sir John Barcroft Centenary Symposion, 1974). Knill et al. (1976) studied respiratory load compensation in full-terms during state 1 and state 2. The authors applied elastic loads to the airway during 5 consecutive breaths, they monitored tidal volume and mask pressure. Motion of the rib cage and of the abdominal wall were simultaneously monitored with magnetometers. During state 1, a load immediately reduces the tidal volume by about 50% but a progressive increase in the tidal volume occurs over the next four loaded breaths. During state 2, load compensation is disorganized with respect both to tidal volume and frequency, the compensation is significantly less. In state 2, there is a marked rib-cage distortion; in state 1, the rib-cage moves as a unit. A similar relation between the type of respiratory movements and state was recently described by Curzi-Dascalova and Plassart (1976).
In the discussion of their results Knill et al., (1976) stated that the major factor determining the degree of interdependence between the move-

ments of the ribs is the state of contraction of the intercostal muscles. The postulated model for the observed differences is a supra-spinal modulation of the gamma system controlling the intercostal muscles spindles. In state 1 this fusimotor drive is higher than in state 2, and perhaps an extra inhibition of the alpha motoneurones exists during state 2. In state 2 due to the absence of, or the small degree of contraction of the intercostal muscles the motion of the ribs depends on local pleural pressures. The lower ribs, responding to the positive abdominal pressure and the direct action of the diaphragm, expands whereas the upper ribs are drawn in by the negative pleural pressure. The direct effect of the distortion is that part of the force generated by the diaphragm is dissipated in this distortion and can not be effectively used for volume exchange.
Furthermore the autors quoted a previous study of Knill and Bryan (1976) in which they could show that rapid distortion of the rib-cage results in premature termination of the inspiration. Thus a weak postural control would not only result in changes in the respiration due to a smaller exchange of volume per unit of contraction of the diaphragm, but also due to a direct influence on the respiratory rate by sudden rib-cage distortions. In animals this phenomenon is described as the intercostal-phrenic inhibitory reflex which would overrule the vagal timing mechanism (see Knill et al., 1976).

For the present discussion one may conclude that some neural mechanisms controlling body posture during the various behavioural states might be of outmost importance for the neural control of breathing. Indeed Scholten (1976) demonstrated a very close link between the regularity of respiration and the amount of gross-body movements. It is tempting to speculate that perhaps a part of this relation might be explained by rapid distortions of the rib-cage. This issue, posture and respiration, is not only theoretically fascinating but may have implications for the understanding of apnoeas in the premature and of the sudden crib-death syndrome in older infants.

6.3. THE EFFECT OF PREVIOUS POSTURAL BEHAVIOUR ON SUBSEQUENT POSTURAL BEHAVIOUR

The actual postural behaviour of the newborn is not fully determined by the two factors discussed previously namely the actual orientation and the actual state. Previous postural behaviour seems to influence the actual posture and the ongoing postural behaviour.
The posture observed during the first state 2 after falling asleep is more active than the posture during the subsequent states 2. The posture during state 1 is determined by the quality and the quantity of the movements during the transition from state 2 into state 1.
Beside these shortterm influences longterm effects seem to exist. Brackbill et al., (1973) demonstrated that newborns, who are nursed in the prone position, are more active and more awake after they are placed in the supine position. In the present study newborns, who are nursed in a side position, tend to return into this side position after they are placed in the supine position. Furthermore in the present study a face preference to the right side is observed. Face preference to the right in neonates is well established in previous studies on much larger material by Gesell and Halverson (1942), Turkewitz and Creighton (1974) and Fulford and Brown (1976).

6.3.1. Preference posture in the newborn

Since all newborns in the present study are full-terms it is not necessary to discuss in detail how the newborn's preference posture would be determined by his postmenstrual age. It should be briefly mentioned that Amiel-Tison (1968) published a scheme based on previous work with Saint Anne-Dargassies, describing several body postures which would be specific for newborns at various postmenstrual ages. Several authors expressed their doubts as to the value of posture as a parameter for estimating the postmenstrual age (Robinson, 1966, and see review Casaer and Akiyama, 1971). Recently Prechtl et al. (1975) could demonstrate that in a group of low-risk preterms there is no clearcut developmental trend in the preference posture; the preference posture is more an individual than an age-related characteristic.
In the present study the moment at which the babies are studied is sufficiently long after the "neonatal shock period" (Escardo and De Coriat, 1960). These authors compared newborns that are born after deliveries during which drugs are used with newborns that are born after spontaneous deliveries. In the first group they observed during the first two postnatal day antigravity postures in awake states that can be compared with the sleeping postures of the present study.
Finally, Beintema (1968) found that during the first ten days of life there is a gradual trend in full-term newborns from an overall flexion posture into a more semiflexed posture for the arms and to an extended posture for the legs. Maekewa and Ochiai (1975) observed higher responses in the recoil reflexes of the arms in neonates whereas recorded EMG responses in the arm flexors were lower in the first days than during the subsequent days. These results might indicate that the initial neonatal posture is more the result of physical properties of the muscles than of active neural control.

The origins of the initial flexion posture and of the face preference to the right in newborns are not understood at present.
A fair agreement exists that the flexion posture of the newborn would somehow be influenced by his prenatal position and posture.
As to the face preference to the right it should be realized that more mothers and nurses are right-handed than left-handed; therefore it is easier for more care-givers to place their newborns in the right-lateral position. (Eggermont, personal communication 1976). In Groningen, however a strict nursing-routine exists in which the lateral position is alternated each feed-feed interval; and still a head-preference to the right seems to exist.
Robson (1968) and Fulford and Brown (1976) tried to explain the face preference to the right by less optimal prenatal mechanical influences on the right hemisphere during the later part of pregnancy or delivery, or by differences in the circulation in the right and the left vertebral arteries during delivery. These last hypotheses have not been proved at all.
Neonatal deformities are shown to be the result of both the behaviour of the foetus and of physical factors which surrounded the foetus. In a large study on more than one thousand pregnancies Dunn (1972, 1975) demonstrated that the main environmental factor resulting in deformities is oligo-hydrammios, which is very pronounced in the foetus with bilateral renal agenesis and in pregnancies with very early rupture of the membranes. The importance of the behavioural repertoire of the foetus for neonatal deformities is clear in infants with spina-bifida at the thoracic or lumbosacral level, who cannot move their legs. These newborns show deformities of legs and feet while they have normal upper extremities.

However, for such deformities trophic influences may play an important role. That the interaction between foetal behaviour and prenatal environment is also relevant under normal conditions is much more difficult to demonstrate. Prechtl and Knol (1958) showed that newborns after breech delivery have a different neonatal neurological behaviour although they are paediatrically and neurologically normal. Newborns born after breech position with extended legs show significantly more extended leg postures and have decreased withdrawal reflexes but increased magnet responses, whereas babies born after breech presentations with flexed legs show the opposite behaviour. Newborns born after face presentations, are observed with hyperextended head postures. Are such differences the result of physical properties of muscles and joints or do they reflect differences in neural control ?

6.3.2. Posture and postural behaviour in utero

Accepting the prenatal posture as an explanation for the postnatal posture is not a final answer. Since remaining problem is then; why is the posture in utero a flexion posture? A similar problem remains for the neonatal head preference to the right; supposed differences in mechanical load on sternocleidomastoid muscles and other neck and trunk muscles during descent and delivery do not explain the preference posture observed in babies born after a breech delivery and after caesarian section. Furthermore, Prechtl (unpublished data, 1976) found that the face preference to the right exists also in prematures having no or minimal constrained head position in utero.
Therefore, further attempts should be made to answer the questions that were raised and partially answered by De Snoo in 1918 : why are 96% of the foetuses in utero in a cephalic presentation and why are 65% of these foetuses in the left occiput anterior postion? De Snoo (1918) after studying 17,000 pregnancies enumerated the following physical factors that influence the intrauterine posture : the effect of gravity and inertia, the movements and postural behaviour of the mother, the fact that the foetal head is heavier than the foetal body, the shape of the uterus (especially the widening of the lower part together with the changes in the supporting fixation ligaments), the relative shapes of foetal head and pelvic ring, (which make the latter a good adaptor for the former) and the structure of the uterine muscle fibers, which may promote a longitudinal alignment of the uterine content. De Snoo considered all these physical-anatomical factors together insufficient to explain the 96% of cephalic presentations. Since babies who died in utero and also malformed babies show a much higher amount of transverse and breech presentation than normal babies, De Snoo (1918) and Liepmann and Danelius (1932) postulated that some foetal activity should be available to explain the longitudinal cephalic presentation.
Langreder (1949, 1950) formulated a series of hypotheses which until now have not yet been tested. Langreder (1950) suggested a "fötale Ruhelage" and a "fötale Bewegungslage". For the foetus in the most frequently occurring dorso-anterior cephalic orientation the "Ruhelage" would be guaranteed when the mother is upright. The foetal back would be supported by the uterus and the abdominal wall. However, when the mother is lying supine the foetus would come into a "Bewegungslage". With combined information from his vestibula and from his proprioceptive and tactile receptors the foetus, who is in prone, would then start crawling forwards. Langreder speculated also that the Moro reflex would be an intrauterine stabilization reflex, which is absent in dead foetuses and in foetuses

with focomelia, resulting in a much higher incidence of cord circumduction around the neck.
This discussion on prenatal developmental neurology is rich in speculations and poor in facts.

A few facts, however, have recently been established and will therefore be mentioned in this discussion.
The foetus is under the influence of gravity, since the specific gravity of the foetus, being 1.055 to 1.058, is greater than the specific gravity of amniotic fluid which is 1.008 to 1.009; therefore the foetus sinks in utero (Wood, 1970). Reinhold who studied foetal movements with the *B-scan ultrasound technique* using a rapid picture formation method (Reinhold, 1971, 1972a, 1973 and 1975) observed foetal movements from the 7th week of gestation onwards. Between the 10th and the 12th week of gestation two types of intrauterine movements can be identified : one type of movement starts with a strong and sudden movement of the whole body, the foetus changes position in the amniotic cavity, frequently the body is kicked away from the amniotic wall and subsequently the foetus settles down.
The second type of movement is slow and inert, the position of the foetus is only slightly changed, only parts of the body, namely the extremities, move. After the 16th week, the drop after the sudden movement is faster than before the 16th week; this may be due to the fact that the foetus becomes relatively heavier. From these observations the partial influence of gravity during prenatal life is a proved fact.
This ultrasound technique is also the first technique that allows measurements of the amount of space that is available for the foetus. (Reinhold 1972b). Up to the 16th week there is space enough for the foetus to move freely . From the 16th week onwards the foetus is restricted and can no more move freely but he can still turn around. After the 34th week of gestation changes from breech to head and vice-versa are still observed but such changes require at least three strong and long lasting movements, the whole procedure lasts over one minute of time (Reinhold personal communication, 1974). Up to the 20th week it is possible to see the whole foetus on a B-scan picture. In this period the foetus is frequently in supine and shows extended postures. After the 20th week a semiflexed posture becomes more and more the predominant resting posture (Reinhold personal communication, 1974).
Concepts in medicine on the intrauterine posture and on the available place in utero showed strong differences during history (see figure 6.1). In the 17th and 18th century, on several paintings the foetus was represented as floating around with quite some variation in the orientation and posture inside a soft uterine sac. Later, at the end of the 19th century, under the influence of anatomists who autopsied gravid women using frozen preparation techniques, quite different pictures emerged. The foetus was represented packed and compressed as much as possible inside a tight uterine wall. This picture persisted for too long in textbooks, as if there is not the daily experience of mothers feeling and observing movements through the uterus and the abdominal wall. Proof that the painters are correct was brought in the early area of radiology, when the danger of too long and too frequent exposures of the foetus and of the mother were not yet know. Warnekros (1925) and Liepmann and Danelius (1932) made photographs during normal pregnancies mainly between the 7th month of gestation and delivery. These authors could demonstrate that the tightly compressed foetus as described from the frozen anatomical preparations does not exist in vivo. The head, the vertebral column and the extremities are found flexed of semiflexed but also sometimes extended.
In series of photographs of the same foetus quite some variations in posture is observed. Both authors documented a breech pregnancy that

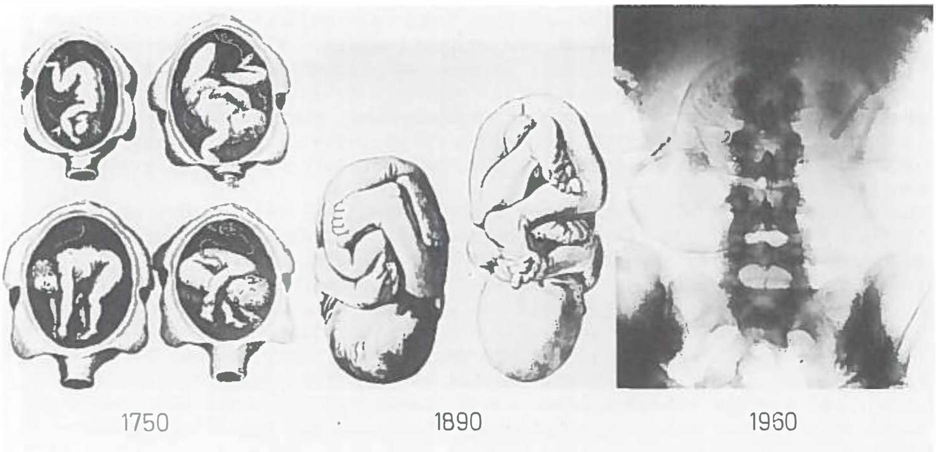


Figure 6.1. Concepts in medicine on intrauterine posture. Note the difference in the degree of freedom between the representation from "La Comare Levatrice", 1750, and the representation based autopsy studies performed at the end of last century, 1890. (Both illustrations are derived from Liepmann and Daneluis, 1932).
Present studies with foetography, 1960, confirms that the '1750 concept' is correct. I selected this foetography from a series of 30 foetographies, made after the 30th week of gestation by Professor Dr. I. Brosens in Leuven and Professor Dr. H. Huisjes in Groningen.

turned spontaneously into a cephalic presentation a few days before delivery. Later the number of observations on normal pregnancies became very limited, sinc X-ray-exposure today is only considered as justified on diagnostic indication. Utzuki and Hashidzume (1941), Brosens et al. (1969), Wiesenhaan (1972) and Daw (1973) showed examples of foetuses in vivo by means of foetography techniques using radiopacque substances with an affinity for the foetal skin. It is amazing how close the artistic reconstructions of Liepmann and Danelius (1932) and the documents with the foetographic techniques come to the representations of the painters in the 17th and 18th century.
Thus from these data it appears that the intrauterine posture is not a passive imposed configuration of head, body and extremities but that the intrauterine posture is a neutral posture around which a large degree of movement is possible.

In this study it is clearly demonstrated that in neonatal life postural behaviour and the behavioural state are very closely related phenomena; therefore a relevant question about the prenatal period would be : are there prenatal behavioural states ?
Two lines of research have recently investigated prenatal periodic phenomena : the first line is the study of the rest-activity cycle in utero, the second line is the study of prenatal respiration and its relation to the behavioural states.
The existence of an intrauterine behavioural state cycle is now well established for lambs, cows, guinea pigs, rabbits, and monkeys (Astic and Jouvet-Monnier, 1969, Dawes et al., 1970, 1972, Ruckebusch and Barbey, 1971, Ruckebusch, 1972, Merlet-Bénichou, 1973 and Martin et al., 1974).

In man data on intra-uterine state cycles are available from transducer recordings of foetal activity and from long lasting foetal EKG recordings (see Sterman, 1967, see Sterman and Hoppenbrouwers, 1971).Jeannerod (1969), Sterman and Hoppenbrouwers (1971) in man, and Ruckebusch (1971, 1972) in cows could demonstrate that foetal activity is influenced by the activity of the mother. Ruckebusch demonstrated that foetal activity is not so much influenced by the amount of activity of the cow but more by what the cow is actually doing, i.e. walking around, eating grass or ruminating.
The second line of research is the study of prenatal respiratory movements. Ahlfeld (1905), Windle (1940) and Barcroft (1946), described foetal thoracic movements resembling breathing in human and animals. Windle (1940) stated that intra-uterine "breathing" is abnormal and a sign of intrauterine stress. A strong and new input to this work came from the Nuffield Institute of Medical Research in Oxford (Dawes et al., 1970, 1972, Boddy and Robinson, 1971, Boddy and Mantell, 1972, Dawes, 1974) and from the work of Merlet in Paris (Merlet et al., 1970, Merlet-Bénichou, 1973). Both these research teams could demonstrate in lambs that foetal thoracic movements occur in utero under physiological conditions and are related to the behavioural state cycle : they occur only or mainly during the rapid eye movement sleep (state 2?). Recently these observations in animals could be extended by observations in human using ultrasound techniques or force tranducers (Boddy and Robinson, 1971, Boddy and Mantell, 1972).

In the context of these prenatal data the finding in the present study that previous nursing position may affect subsequent posture and postural behaviour becomes important. In utero during the last months of pregnancy the foetus rests in a semiflexed posture. During an "in utero state 2" the length and the physical properties of intra- and extrafusal fibres will be in a state of equilibrium according to the foetal position. During state 1 there might be an active gamma control of the muscle-spindles leading to an alpha motoneuron activation, which results in an active posture, i.e. a posture that can resist certain postural loads such as they occur due to the activities of the mother. Such actively controlled posture will again influence the passive visco-elastic properties of the intra- and extrafusal fibres.
After delivery the prenatal flexion posture is enhanced as a result of the full exposure to the effect of gravity. This environmental change directly affects the activity of the muscle-spindles but it affects also indirectly the alpha and gamma system by means of its influence on spatial receptors such as the vestibula, the proprioceptive and the exteroceptive receptors. During the subsequent days the newborn programmes other movements and postures in its new environment, i.e. the postures during sucking, while he is carried and during head-lifts. This leads to new calibrations of the peripheral receptors especially of the spindles, so that a new preference posture emerges, i.e. the extended leg posture which is observed after the first week of extrauterine life.

Chapter 7

CONCLUDING REMARKS

7.1. POSSIBLE CLINICAL IMPLICATIONS

The fact that in a group of normal newborns previous posture has an effect on subsequent postural behaviour makes it very plausible that the squint baby syndrome (see Fulford and Brown, 1976) and infant scoliosis may result from the slightest imbalance between a postural preference to the right or to the left and the capacity of a newborn to react against the influences of gravity. In slightly hypokinetic and hypotonic infants a head preference may sooner than previously expected result in a rather rigid head preference. Visco-elasticity changes in the neck muscles will result from the preference posture. Subsequently the setting of the muscle receptors will show an imbalance between the preference and the non preference side and this in turn may affect the further postural behaviour of the newborn. Once this imbalance has resulted in structural asymmetries of the head and the thorax the preference is definite up to the moment that the baby or the care-giver changes the orientation of the infant. The squint baby syndrome features diminish at the moment that the baby starts sitting (Fulford and Brown, 1976).

The finding that odd postures of the extremities may result in an increased amount of motor activity has the practical implication that for newborns with neonatal adaptation problems such odd postures should be corrected by the care-giver to avoid inadequate wasting of energy into this type of strong motor activities.

In the light of the present findings it is not suprising that items which are related to postural behaviour (postural behaviour in prone and in supine, the pull to sit test, the headcontrol in the pull to sit test and the postural behaviour in supine and in prone suspension) have been included in the neurological examination as very sensitive parameters (Prechtl and Beintema, 1964). Dubowitz (1969) advocated exactly these parameters to evaluate and to follow up floppy infants. If a baby is found to be abnormal during such a neurological examination a further differentiation of the underlying disorder may be obtained from the systematic study of the baby's postural behaviour and the corresponding modulation in muscle-activities in the various behavioural states, in different orientations and during specific behavioural programmes such as sucking and orienting. For objectivating the possible effects of physical therapy and of pharmacological agents, the polygraphic techniques as presented in this study look very promising.

7.2. FINAL METHODOLOGICAL REMARKS

In the present study the individual differences are such that the only legitimate design is to use each baby as his own control. For future studies, that are set up to study mechanisms more than to collect norms, a similar approach is advocated.

In the various experimental methods used those methods, that restrict the baby's free behaviour, do not permit concrete conclusions during the awake states, since the awake babies have to be pacified frequently. In future studies one should try to stay as close as possible to biologically relevant behaviour, since otherwise the only conclusion that can be drawn will be under which conditions the baby reacts against the imposed experimental restrictions and under which he does not react. In the differentiation between normal and deviant newborns such experiments might result in a trivial conclusion that hypoactive babies react less than hyperactive babies. The experiment with the transversal rocking appears appropriate to standardize postural loads.

During this study the effect of non-nutritive sucking on postural behaviour is amazing therefore, for future studies in infants it should be mentioned whether a pacifier is used or not.

Before final extrapolations can be drawn from the present results as to the nursing situation one should remember that during our observations the babies are uncovered. In the routine nursing situation (except for the baby lying in the incubator) the baby is covered, this fact results in an extra restriction for movements and in an extra exteroceptive input. In future experiments covering the babies with a transparent blanket might be one of the solutions to come closer to the nursing situation.

Finally detailed observations illustrated by time-lapse photography together with recordings of surface-EMG and state-related physiological concomitants, seem to be the most adequate method for continuing this line of research.

SUMMARY

The present study reports the results of observations and polygraphic recordings on postural behaviour in sixty-eight newborn infants.

The introduction of the first chapter situates the present study in the context of previous and present research at the Institute of Developmental Neurology in Groningen. Subsequently the main question is formulated : *do human newborns have a body posture?* The clinical relevance of the study is then discussed. Finally the approach used in this study is compared with approaches used in previous studies on postural behaviour and postural mechanisms in both man and animals.

In the second and third chapters the subjects and the methodology are respectively described. In paragraph 3.6 the design of the present study and some of the pitfalls in designing and carrying out this study are discussed.

Chapter four is a qualitative description of postural behaviour of newborns placed in the prone, the supine and the side position. Subsequently some observations on postural behaviour of newborns carried by their care-givers and of sucking newborns are described. The importance of position and of the behavioural state becomes obvious from these observations.

Chapter five is the longest, after an introduction devoted to the two concepts of "state", four more sections are developed.
The first section is a comparison of postural behaviour of newborns placed in a supine horizontal and in a supine semi-upright position. After a brief qualitative description, quantitative results on the behavioural states, the type and the amount of gross-motor activities, the respiration, the heart-rate and the rapid eye movements are reported. The conclusion of this section is that an increase in gravitational load affects neonatal behaviour.
The second section is a similar comparison of postural behaviour in the supine position with postural behaviour in the prone position. The major finding in this section is that previous postural behaviour may affect present postural behaviour. Since the number of observations is small and since at least two previous factors are relevant, namely the head preference and the previous nursing position further studies are needed to elucidate this problem.
The third section describes postural reactions due to imposed positional changes, namely transversal and longitudinal rocking experiments. In a technical note various aspects of the apparatus used in the rocking experiments are extensively described. The results of these experiments demonstrate that definite differences in postural control do exist in the various behavioural states.
In the last section of chapter five changes in postural behaviour are related to changes in muscle activity as recorded with an improved surface electromyographic technique. In a technical note problems encountered with surface electromyography and some improvements of this technique are described.

Chapter six is a general discussion of the results of this study in relation to data from the literature on structural and functional development of the nervous system in the perinatal period. The discussion is centered on the three interacting factors which are shown in this study to be relevant for postural behaviour in the neonate : the newborn's position, his behavioural state and his previous postural behaviour. A separate paragraph is devoted to the relationship between posture and respiration.

Chapter seven consists of concluding remarks on possible clinical implications and on methodological aspects relevant for future research.

SAMENVATTING

In deze studie wordt het houdingsgedrag van achtenzestig neonati beschreven bij middel van observaties en polygraphische registraties.

In het eerste hoofdstuk wordt de plaats van dit onderzoek in de onderzoekslijn van het Instituut voor Ontwikkelingsneurologie te Groningen bepaald. Aansluitend wordt de eigenlijke vraagstelling geformuleerd : *Heeft de neonatus reeds een houding?* Het klinische belang van dit soort onderzoek wordt vervolgens besproken. Tenslotte wordt de benaderingswijze gebruikt in dit onderzoek vergeleken met andere benaderingswegen, die gebruikt werden in onderzoek met betrekking tot houding en houdingsmechanismen bij de mens en het proefdier.

Hoofdstuk twee beschrijft de selectie criteria voor de te bestuderen pasgeborenen. Hoofdstuk drie beschrijft de gebruikte methodologie. In paragraaf 3.6 worden moeilijkheden en problemen die ondervonden werden bij het opzetten en uitvoeren van deze studie besproken.

Hoofdstuk vier is een kwalitatieve beschrijving van het houdingsgedrag van pasgeborenen die op de rug, op de buik of in zijligging liggen. Aansluitend volgen beschrijvingen van de houding van neonati die gedragen worden en van pasgeborenen die zuigen.
De resultaten van dit hoofdstuk maken duidelijk hoe belangrijk positie en gedragstoestanden zijn voor het houdingsgedrag van de neonatus.

Hoofdstuk vijf is het grootste hoofdstuk. Na een inleiding die de twee begripsomschrijvingen van de "state", de "gedragstoestand", bespreken volgen er vier delen met kwantitatieve gegevens.
Het eerste deel omvat een vergelijking tussen het houdingsgedrag van boorlingen die op hun rug liggen met het houdingsgedrag van dezelfde boorlingen terwijl ze half rechtop liggen in een babystoeltje. Na een korte kwalitatieve beschrijving volgen kwantitatieve resultaten over de gedragstoestanden, de motoriek, de ademhaling, de oogbewegingen en het hartritme. Het belangrijkste besluit van dit deel is dat een toename in de belasting van het houdingskontrole systeem resulteert in significante veranderingen in het neonataal gedrag.
Het tweede deel is een soortgelijke vergelijking tussen houdingsgedrag van neonati die op hun rug liggen met het houdingsgedrag van dezelfde neonati terwijl zij op hun buik liggen. Het belangrijkste resultaat van deze vergelijking is dat voorafgaand houdingsgedrag mogelijk het actuele houdingsgedrag beïnvloed. Het aantal observaties is echter klein in deze studie en er is meer dan één factor in het voorafgaande houdingsgedrag die van belang zou kunnen zijn; namelijk zowel de voorkeurshouding van het hoofd als de positie waarin het kindje verpleegd wordt. Voor dit probleem is verder onderzoek zeker aangewezen.
Het derde deel van hoofdstuk vijf beschrijft houdingsveranderingen uitgelokt door opgelegde bewegingen zoals het schommelen van de boorling rond een transversale of een longitudinale as. In een technische nota worden het schommelapparaat en de hoofdhouder uitvoerig beschreven. De

resultaten van deze experimenten tonen overduidelijk dat er verschillen zijn in de houdingskontrole, naargelang de gedragstoestand van de neonatis. In het vierde en laatste deel van hoofdstuk vijf wordt getracht een relatie te leggen tussen observeerbare houdingsverschijnselen en registreerbare spieractiviteiten. Deze spieractiviteiten worden opgeschreven bij middel van een verbeterde oppervlakte-electromyographie . In een technische nota worden problemen en enkele oplossingen van problemen met de oppervlakte-electromyographie besproken.

Hoofdstuk zes is een algemene discussie van de resultaten van deze studie in relatie tot gegevens uit de literatuur, die betrekking hebben op de structurele en de functionele maturatie van die delen van het zenuwstelsel, die met houdingskontrole kunnen te maken hebben. Deze discussie is opgebouwd rond de bespreking van drie factoren die in dit onderzoek van belang waren voor actueel houdingsgedrag : de positie van de pasgeborene, zijn gedragstoestand en zijn voorafgaand houdingsgedrag. In een aparte paragraaf wordt de relatie houding en ademhaling besproken.

Hoofdstuk zeven bestaat uit een reeks slotbemerkingen over enerzijds mogelijke klinische toepassingen en anderzijds over de te gebruiken methoden voor verder onderzoek.

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